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Office of Solid Waste
and Emergency Response
Washington DC 20460

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December 1985

Solid Waste

EPA

Report To Congress

Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale

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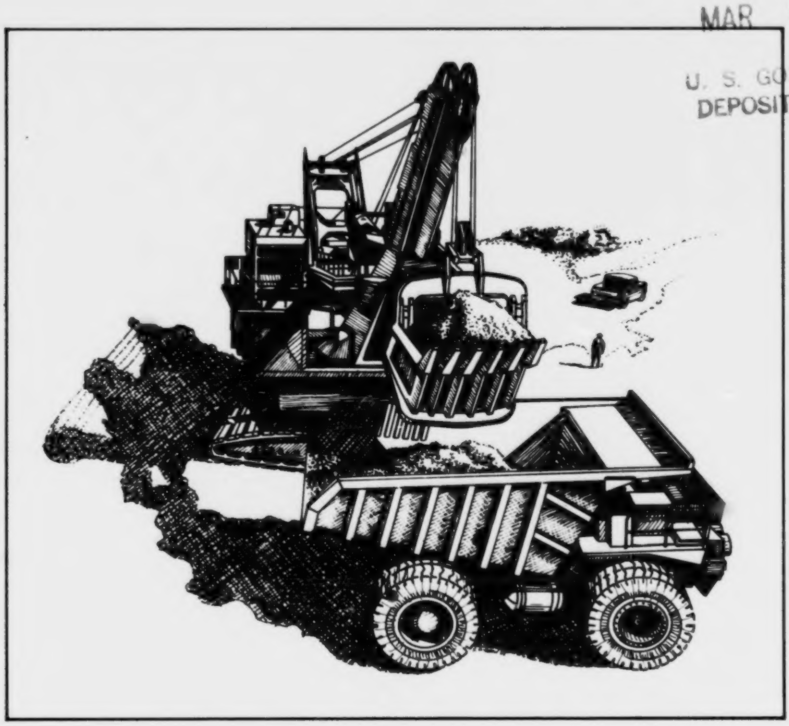

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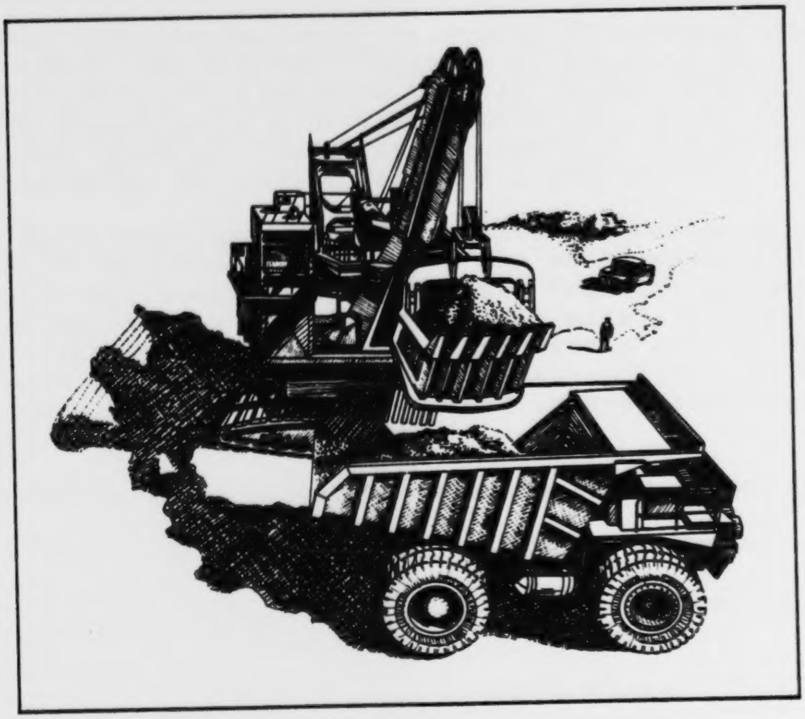

December 31, 1985
U.S. Environmental Protection Agency
Office of Solid Waste

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

DEC 3 1 1985

THE ADMINISTRATOR

Honorable George Bush
President of the Senate
Washington, D.C. 20510

Dear Mr. President:

I am pleased to transmit the Report to Congress on "Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale" presenting the results of studies carried out pursuant to Sections 8002 (f) and (p) of the Resource Conservation and Recovery Act of 1976, as amended, (42 U.S.C. §§6982 (f) and (p)).

The Report provides a comprehensive assessment of possible adverse effects on human health and the environment from the disposal and utilization of solid waste from the extraction and beneficiation of ores and minerals. All metal, phosphate, and asbestos mining segments of the United States mining industry are included in the assessment. Waste categories covered include mine waste, mill tailings, and waste from heap and dump leaching operations.

The Report and appendices are transmitted in one volume.

Sincerely yours,

Lee M. Thomas

Enclosures

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

DEC 31 1985

THE ADMINISTRATOR

Honorable Thomas P. O'Neill
Speaker of the House of Representatives
Washington, D.C. 20515

Dear Mr. Speaker:

I am pleased to transmit the Report to Congress on "Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale" presenting the results of studies carried out pursuant to Sections 8002 (f) and (p) of the Resource Conservation and Recovery Act of 1976, as amended, (42 U.S.C. §§6982 (f) and (p)).

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EXECUTIVE SUMMARY

This is the executive summary for the Environmental Protection Agency's Report to Congress on Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale. EPA has prepared this report in response to the requirements of Sections 8002(f) and (p) of the Resource Conservation and Recovery Act (RCRA). Section 8002(f), a part of RCRA when it was originally enacted in 1976, directed EPA to perform a

> detailed and comprehensive study on the adverse effects of solid wastes from active and abandoned surface and underground mines on the environment, including, but not limited to, the effects of such wastes on humans, water, air, health, welfare, and natural resources....

Section 8002(p), which Congress added to RCRA when it amended the Act in 1980, required EPA to conduct a

> detailed and comprehensive study on the adverse effects on human health and the environment, if any, of the disposal and utilization of solid wastes from the extraction, beneficiation, and processing of ores and minerals....Such study shall be conducted in conjunction with the study of mining wastes required by subsection (f)....

Under the 1980 amendments, EPA is prohibited from regulating solid waste from the "extraction, beneficiation, and processing of ores and minerals" under Subtitle C of RCRA until at least 6 months after the Agency completes these studies and submits them to Congress. The purpose of this prohibition is to exempt these wastes temporarily from the requirements of the RCRA hazardous waste management system. After submitting the required studies, holding public hearings, and providing the public with an opportunity to comment, the Administrator must "determine to promulgate regulations" or "determine such regulations are unwarranted" for these mining wastes.

If EPA decides to regulate mining wastes as hazardous under RCRA Section 3004(x), which Congress added to the Act as part of the Hazardous and Solid Waste Amendments of 1984, EPA may modify provisions of these regulations pertaining to liquids in landfills, land disposal restrictions, and minimum technology requirements, as they apply to mining wastes. In doing so, EPA may

> take into account the special characteristics of such wastes, the practical difficulties associated with implementation of such requirements, and site-specific characteristics, including, but not limited to, the climate, geology, hydrology and soil chemistry at the site, so long as such modified requirements assure protection of human health and the environment.

This report addresses wastes from the extraction and beneficiation of metallic ores (with special emphasis on copper, gold, iron, lead, silver, and zinc), uranium overburden, and the nonmetals asbestos and phosphate rock. The Environmental Protection Agency's findings on oil shales are summarized in Appendix A of this report. EPA selected these mining industry segments because they generate large quantities of wastes that are potentially hazardous and because the Agency is solely responsible for regulating the waste from extraction and beneficiation of these ores and minerals. Likewise, the Agency excluded from the study wastes generated by the clay, sand and gravel, and stone mining segments, since it judged wastes from these sources less likely to pose hazards than wastes from the industries included. EPA also excluded uranium mill tailings wastes, because the Agency has already submitted a report to Congress on uranium mill tailings. The Agency excluded wastes from coal mining and beneficiation, because both EPA and the Department of the Interior play a role in their regulation, and it is not clear whether Congress intended coal mining to be included within the scope of the studies conducted in response to Sections 8002(f) and (p) of RCRA. Finally, EPA excluded large-volume processing wastes. On October 2, 1985, EPA proposed to reinterpret the scope of the mining waste exclusion as it applies to processing wastes, leaving only large volume processing wastes excluded (FR 401292). Other wastes from processing ores and minerals that are hazardous would be brought under full Subtitle C regulation after promulgation of the reinterpretation, and would therefore not be included in the scope of a subsequent Report to Congress on processing wastes. The large-volume processing wastes that remain within the exclusion would be studied and a Report to Congress prepared to complete EPA's response to the RCRA Section 8002(p) mandate.

The remainder of this Executive Summary consists of five sections. First, we provide an overview of the industry segments covered in this report. Next, we describe management practices for mining wastes. Then we discuss the potential danger to human health and the environment that mining wastes pose. Following this, we estimate the costs that regulating mining wastes could impose under several scenarios and briefly outline the effects of these costs on product prices. Finally, we present the Agency's conclusions and recommendations.

OVERVIEW OF THE NONFUEL MINING INDUSTRY

The nonfuel[1] mining industry is an integral part of our economy, providing a wide range of important products. The value of raw nonfuel minerals is about 1 percent of the Gross National Product (GNP), and products made from these raw materials account for about 9 percent of the GNP.

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[1] For the purposes of this report, the nonfuel mining industry is defined to include uranium, although processed uranium may be used as a fuel.

The number of active mines varies from year to year, depending on economic factors; in 1980 (the most recent year for which complete data are available from the U.S. Bureau of Mines), there were about 600 metal mines and about 12,000 nonmetal mines. Most of the nonmetal mines were clay, sand and gravel, and stone mines, and thus fall outside the scope of this report. In the industry segments that this report covers, a few large mines generally produce most of the ore and generate most of the waste.

Ores occur only in certain geologic formations, so much of the mining within an industry segment is concentrated in a few locations. Because the raw ore must be extracted from the earth, and only a small percentage of the mined rock is valuable, vast quantities of material must be handled for each unit of marketable product. Much of this material is waste.

Mine waste is the soil or rock that is generated during the process of gaining access to the ore or mineral body. Tailings are the wastes generated by several physical and chemical beneficiation processes that may be used to separate the valuable metal or mineral from the interbedded rock; the choice of process depends on the composition and properties of the ore and of the gangue, the rock in which the ore occurs. Some low-grade ore, waste rock, and tailings are used in dump or heap leaching, a process that the mining industry considers a form of beneficiation and one that involves spraying the material with acid or cyanide to leach out metals. This process is most widely practiced in the copper, silver, and gold mining segments, and the associated wastes are termed dump/heap leaching wastes. The final waste type is mine water, water that infiltrates the mine during the extraction process. Table ES-1 lists the types and quantities of mining wastes generated by each mining segment of concern.

Extraction and beneficiation produce large quantities of waste. The segments covered in this report generate 1 to 2 billion tons of waste each year and have so far produced over 50 billion tons of waste. Copper, iron ore, uranium, and phosphate mining operations are responsible for more than 85 percent of this total volume of waste and continue to account for most of the waste presently generated. As lower and lower grades of ore are mined, more waste per unit of product is generated.

Approximately one-half of the waste generated by the segments of concern is mine waste, and one-third is tailings. Most of the mine waste is from phosphate, copper, iron ore, and uranium mining; the majority of tailings are from the copper, phosphate, and iron ore segments. Only the copper, gold, and silver mining industries presently generate dump or heap leach waste. The following section discusses how industry currently manages these wastes.

WASTE MANAGEMENT PRACTICES

Mine waste, tailings, heap and dump leach wastes, and mine water can be managed in a variety of ways. Figure ES-1 provides an overview of waste management practices. Waste management practices include recovery operations, volume reduction, treatment, onsite and offsite use, and waste siting and disposal. For mine waste and tailings, disposal constitutes the major practice; about 56 percent of mine wastes are currently managed by disposal in piles, and about 61 percent of tailings are managed in tailings ponds. About 30 percent of mine waste and tailings are used on site in leaching operations,

Table ES-1 Waste Generation

(Millions of Metric Tons in 1982)

Mining industry segment	Mine waste	Tailings	Leaching wastes	Total
Metals:				
Copper	124	178	200(dump)	502
Gold	39	24	11(heap)	74
Iron	102	75	-	177
Lead	2	9	-	11
Molybdenum	24	6	-	30
Silver	20	6	<1(heap)	26
Uranium	73	NA	-	73
Zinc	1	6	-	7
Other metals	23	3	-	26
Subtotal	408	307	211	926
Nonmetals:				
Asbestos	4	2	-	6
Phosphate	294	109	-	403
Subtotal	298	111	-	409
TOTAL	706	418	211	1,335

Source: Estimated by Charles River Associates 1985 based on BOM 1983.

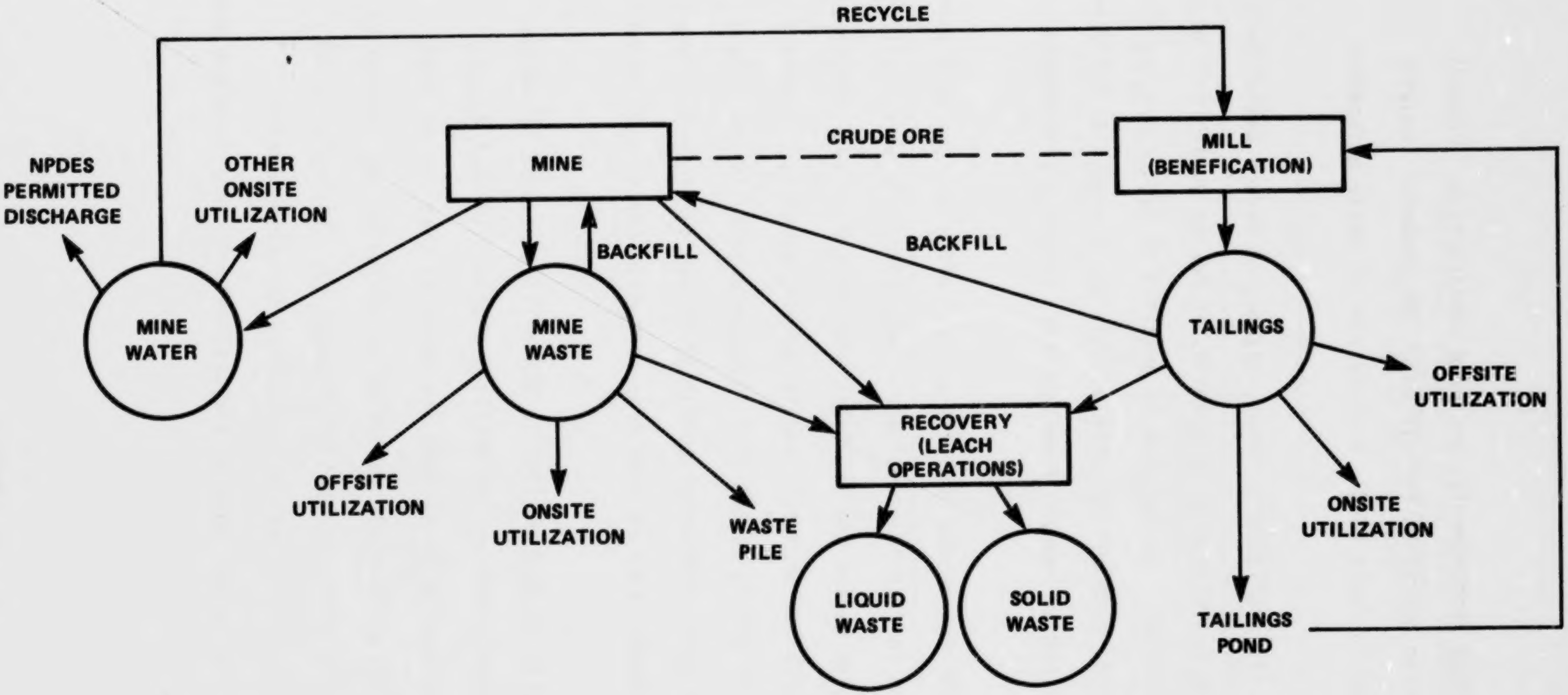

Figure ES-1 The mining waste management process construction of tailings impoundments, and road construction. Present disposal and utilization practices for all metal and nonmetal industry segments are presented in Table ES-2. A discussion of waste management practices follows.

Several methods are available to treat, change, or reduce wastes before disposing of them. In operations using cyanide, it may be possible to oxidize the cyanide before disposal. It may also be possible to remove pyrites from tailings, thus reducing, although not eliminating, their potential for forming acid. Finally, water can be removed from tailings, creating a thickened discharge.

Extraction and milling wastes can also be used off site; the most common use of these wastes is in road construction. Researchers are investigating other uses for both mine wastes and tailings, such as use in soil supplements, in wallboard and brick/block products, and in ceramic products. However, it is unlikely that use of mining wastes will increase greatly in the future, because in most cases their commercial potential is not sufficient to overcome the economic disadvantages, such as high transportation costs, associated with their use.

Mine water can also be used on site in the milling process as makeup water or for dust control, cooling, or drilling fluids. In most cases, however, the amount of mine water exceeds the quantity that can be used.

The majority of the solid waste generated in mining is not reduced by any of the methods described above and must be disposed of. Siting disposal facilities in appropriate locations is fundamental to environmental protection, and other management methods are available for ameliorating waste disposal problems.

Table ES-2 Present Mining Waste Disposal and Utilization Practices (Millions of Metric Tons/Year)

Practice	Waste type and volume	
	Mine waste	Mill tailings
Pile	569	-
Backfill	86	21
Onsite utilization	313	141
Impoundments	-	267
Offsite utilization	43	8
TOTAL	1,011	437

During active site life, during closure, and in the post-closure period, facilities could employ engineering controls to prevent erosion, to keep leachate out of the ground water, or to remove contaminants introduced into ground water. However, EPA data on management methods at mining facilities indicate that only a small percentage of mines currently monitor their ground water, use run-on/runoff controls or liners, or employ leachate collection, detection, and removal systems. EPA has not determined the circumstances under which these waste measures would be appropriate at mine waste and mill tailing disposal sites.

POTENTIAL DANGER TO HUMAN HEALTH AND THE ENVIRONMENT

The potential dangers posed by wastes from nonfuel mining and beneficiation vary greatly and depend on the industry segment; the beneficiation process; and site-specific geologic, hydrologic, and climatic factors. Some rock is naturally high in metals or radionuclides. Some beneficiation processes use acids and cyanides. Mine waste, tailings, and mine water can contain these materials and also be acidic or alkaline. Hazardous substances could leak into the environment, polluting the soil and surface and ground water and endangering receptor populations.

The Agency has not yet performed a quantitative risk assessment. Risk analysis can provide a quantitative estimate and allow EPA to distinguish between the risk posed by current, past, and alternative management practices. Additionally, it will enable the Agency to evaluate how site-specific factors such as hydrology, proximity to surface water, climate, distance from human populations, type and sensitivity of aquatic populations, closeness to drinking water supplies, and the chemical and physical composition of the waste itself affect risk.

EPA evaluated the potential dangers posed by mining wastes by testing for the RCRA characteristics of corrosivity and EP toxicity and by assessing the level of several other substances in these wastes. A substance was considered corrosive if the pH was equal to or less than 2 (acidic) or equal to or greater than 12.5 (alkaline). A substance was determined to be EP toxic if, using a specified leaching procedure, it exceeded the National Interim Primary Drinking Water Standards (NIPDWS) for an EP toxic metal by a factor of 100.

Only samples from copper dump leach met the RCRA characteristic for corrosivity because of low pH, but pH values were quite low (more than 2 and less than or equal to 4) for many samples from the copper and other metals industry segments and for one sample from the molybdenum segment. Only one sample, from the "other" metals industry segment, met the RCRA characteristic for corrosivity because of high pH. In addition, one sample each from the gold and silver industry segments, three from the copper industry segment, and four from the other metals segment had relatively high (more than 10 and less than or equal to 12.5) pH values. EP toxic results were obtained for at least one sample from copper dump/heap leachate, gold tailings and mine waste, lead mine waste and tailings, silver tailings and mine waste, and zinc tailings. EPA's water quality criteria for the protection of aquatic life are generally set at levels at lower concentrations than those established by the NIPDWS.

Another potential threat to organisms and the environment is acid formation. Wastes with the highest acid formation potential are in the copper, gold, and silver industry segments, although the degree of potential harm varies with the mineral content of wastes and soils (some wastes and soils have neutralizing chemicals), amount of precipitation (more increases the potential for acid drainage), and other factors not evaluated.

Of the other potentially hazardous constituents considered, cyanide was detected in copper and gold tailings ponds and gold heap leachate. Radioactive material was found in uranium and phosphate mine waste samples and in phosphate tailings. Although only asbestos mining wastes were tested in this study for asbestos content, effluent guideline data suggest that asbestos may be present in wastes generated by some metal mining industry segments. EPA has insufficient data to evaluate the hazard, if any, posed by asbestos contained in metal mining wastes.

Based on these sampling results, EPA estimates that the copper mining segment generates 50 million metric tons of RCRA corrosive waste annually. The gold, lead, silver, and zinc industry segments generate a total of 11.2 million metric tons of RCRA EP toxic waste annually. EPA estimates that 182 million metric tons of copper dump leach are generated annually, and that the gold and silver segments generate a total of 9.3 million metric tons of tailings and 14 million metric tons of heap leach annually. High acid formation potential waste is estimated at 95 million metric tons a year. The phosphate and uranium mining industries generate approximately 443 million metric tons of radioactive waste (with a radioactivity level of more than 5 picocuries/gram, the level established as a "cleanup" standard under the 1983 standards for Protection Against Uranium Mill Tailings). There are also 5 million metric tons of asbestos-containing waste (asbestos content greater than 1 percent by weight) generated each year. Estimated amounts of potentially hazardous wastes are reported in Table ES-3.

Of the estimated 1,340 million metric tons of waste generated annually by metal, asbestos, and phosphate mining, 61 million tons are estimated to be hazardous under current RCRA Subtitle C characteristics. Adding wastes with

Table ES-3 Estimated Amounts of Wastes with RCRA Hazardous Characteristics and Other Wastes Potentially Subject to Regulation as Hazardous Wastes Under RCRA

Category	Annual amount (millions of metric tons)	Source	Potential danger
RCRA Characteristics			
Corrosive	50	Copper leach dump liquor	Ground-water acidification
EP toxic	11	Gold, silver, lead, zinc wastes	Toxic metal ground-water contamination
Other Categories			
Precious metal recovery wastes	9	Gold, silver	Cyanide contamination of surface and ground water
Heap leaching wastes	14[a]	Gold, silver	Cyanide contamination of surface and ground water
Dump leaching wastes	182[a]	Copper dump leach wastes	Massive release of toxic metals and low pH liquids
Radioactive wastes (5 pCi/g)	352 91	Phosphate, uranium	Radon emissions
Acid formation	95	Copper mill tailings	Release of low pH liquids after closure
Asbestos	5	Asbestos mines and mills	Cancer
	755[a]		

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[a] The total annual amount of waste is not equal to the sum of hazardous waste in each category because some wastes are in more than one category. For example, 50 million metric tons of copper dump leach waste are also corrosive, and 4 million metric tons of gold tailings are both EP toxic and contaminated with cyanide.

high acid formation potential, those that contain asbestos, those that are potential candidates for listing because they commonly have high levels of cyanide (greater than or equal to 10 mg/l), and radioactive wastes (radium-226 greater than or equal to 5 picocuries/gram) would increase this total to 755 million metric tons of potentially hazardous waste generated by these mining industry segments each year.

EPA conducted a study to determine whether mining waste management facilities leak and, if they do, whether they release constituents that are of concern. Surface water and/or ground water was monitored at eight representative active mine sites. Results indicate that constituents from impoundments do enter ground water at most sites, but significant increases in the concentrations of hazardous constituents were rarely demonstrated.

Damage cases, however, show that mine runoff and seepage have adversely affected surface and ground water in several mining districts. Sudden and chronic releases of cyanides, acids, and metals have reduced fish populations and the number of other freshwater organisms. However, some of these incidents were caused by waste management practices that are no longer in use.

THE ECONOMIC COST OF POTENTIAL RCRA WASTE MANAGEMENT

EPA examined the wide range of potential costs that regulating mining wastes as hazardous under RCRA could impose on facilities and segments of the mining industry. To examine this range, EPA estimated the incremental costs, those over and above the costs the industry already incurs to manage wastes, for eight regulatory scenarios of varying stringency. EPA constructed these eight scenarios by taking all combinations of four different sets of management standards and two criteria for determining whether wastes are hazardous.

The estimation procedure applied specific information from 47 mines to develop costs at these mines and then extrapolated these results to the universe covered in this report.

The management standards that EPA examined ranged from imposing the full set of RCRA Subtitle C regulations (the most expensive set of management standards, Scenario 1) to requiring only a limited set of requirements: permits, a leachate collection system, a ground-water monitoring system, a run-on/runoff system, and post-closure maintenance (Scenario 4). Under the first criterion for determining whether wastes were hazardous, waste streams failing the Subtitle C characteristics tests for EP toxicity and corrosivity and cyanide wastes from gold metal recovery operations were included as hazardous (Scenario A). Under the second criterion, all wastes captured under the first set were included, as well as (1) wastes from gold and silver heap leach operations, (2) wastes with high acid formation potential, and (3) copper dump leach wastes (Scenario B). Both hazardous waste criteria captured only wastes from the copper, gold, silver, lead, and zinc mining segments.

Estimated costs could be very substantial, depending on the management standards and criteria for defining hazardous waste. Under the most costly combination (the unlikely scenario imposing the full set of RCRA regulations and the most restrictive criterion for determining whether waste is hazardous, Scenario 1B), the annualized costs for the mining segments covered by the assessment were $850 million per year, while for the least costly combination (maintenance and monitoring), the annualized cost was $7 million per year. (Annualized costs resemble mortgage payments, in that they spread the present value of total costs into equal payments over the time period EPA estimates the affected mines will be productive.)

As the previous paragraph demonstrates, costs vary substantially across the different cost scenarios. Generally, the highest cost scenarios are several times more expensive than the intermediate cost scenarios; these, in turn, are several times more expensive than the least expensive. The additional waste management costs incurred by adding Scenario B wastes to the wastes to be regulated are also substantial; the costs of managing all Scenario B wastes would be two to four times higher than the costs of managing only the Scenario A wastes, for any given management standard.

The potential costs of regulation also vary widely for the five individual metal mining segments, both across segments and scenarios. Under all scenarios, the copper industry would incur the largest cost, while the gold industry would bear the second highest lifetime cost.

The additional effects of regulation on some segments of the mining industry could be substantial. For a low-cost scenario, average affected facilities in the zinc segment (the segment most affected by regulatory costs as a percent of direct product cost) would incur costs as high as 5 percent of direct product costs, while under a high-cost scenario a zinc facility could incur costs of 10 percent. Under a high-cost scenario, RCRA compliance costs as a percent of direct product cost for the average affected facility were 21 percent in the lead industry and ranged upward of 120 percent in the copper industry.

CONCLUSIONS

Structure and Location of Mines

EPA focused on segments producing and concentrating metallic ores, phosphate rock, and asbestos, totalling fewer than 500 active sites during 1985. These sites are predominantly in sparsely populated areas west of the

Mississippi but have great diversity in size, product value, and volumes of material handled. Several segments are concentrated primarily in one state: the iron segment is mainly concentrated in Minnesota, lead in Missouri, copper in Arizona, asbestos in California, and phosphate in Florida.

Waste Quantities

Aggregate waste quantities generated were 1.3 and 2 billion metric tons per year in 1982 and 1980, respectively. The accumulated waste (for segments other than coal) is estimated to be approximately 50 billion metric tons. Waste-to-product ratios are generally higher in mining industry segments than in other industrial segments. Some individual mines and mills handle more materials than many entire industries, but 25 percent of the mines studied handled less than 1,000 metric tons per year.

Potential Hazard Characteristics

Of the 1.3 billion metric tons of wastes that EPA estimates will be generated by extraction and beneficiation in 1985, about 61 million metric tons (5 percent) exhibit the characteristics of corrosivity and EP (extraction procedure) toxicity. Another 23 million metric tons (2 percent) are beneficiation wastes contaminated with cyanide. Also, there are 182 million metric tons (14 percent) of copper leach dump material and 95 million metric tons (7 percent) of copper mill tailings with the potential for release of acidic and toxic liquids. If waste with radioactivity content greater than 5 picocuries per gram is considered hazardous, the hazardous volume is 443 million metric tons (34 percent) from the phosphate and uranium segments; if waste with radioactivity greater than 20 picocuries per gram is considered hazardous, the total is 93 million metric tons (7 percent). Four asbestos mines generated about 5 million metric tons (less than 1 percent) of waste with a chrysotile content greater than 5 percent.

Evidence of Environmental Transport

At mine sites, ground-water monitoring is difficult and expensive, and generally is not conducted on a large scale. From short-term monitoring studies at eight sites, EPA detected seepage from tailings impoundments, a copper leach dump, and a uranium mine water pond. However, EP toxic metals of concern did not appear to have migrated during the 6- to 9-month monitoring period. Other ground-water monitoring studies have detected sulfates, cyanides, and other contaminants from mine runoff, tailings pond seepage, and leaching operations.

Evidence of Damages

Incidents of damage (contamination of drinking water aquifers, degradation of aquatic ecosystems, fish kills, and related reductions of environmental quality) have been documented in the phosphate, gold, silver, copper, lead, and uranium segments. There are 13 mining sites on the National Priorities List (Superfund), including five gold/silver, three copper, three asbestos, and two lead/zinc mines. The asbestos Superfund sites differ from other sites in that these wastes pose a hazard via airborne exposure. It is not clear, from the analysis of damage cases and Superfund sites, whether or not current waste management practices can prevent damage from seepage or sudden releases. However, it is clear that some of the problems at abandoned or Superfund sites are attributable to waste disposal practices not currently used by the mining industry.

Waste Management Practices

Site selection for the mine, as well as its associated beneficiation and waste disposal facilities, is the single most important aspect of environmental protection in the mining industry. Most mine waste is disposed of in piles, and most tailings in impoundments. Mine water is often recycled through the mill and used for other purposes on site. Offsite utilization of mine waste and mill tailings is limited (2 to 4 percent). Some management measures (e.g., source separation, treatment of acids or cyanides, and waste stabilization) now used at some facilities within a segment of the mining industry could be more widely used. Other measures applied to hazardous waste in nonmining industries may not be appropriate. Soil cover borrowed from surrounding terrain may create additional reclamation problems in arid regions.

Potential Costs of Regulation

For five metal mining segments, total annualized costs range from $7 million per year (for a scenario that emphasizes primarily basic maintenance and monitoring, for wastes that are hazardous by RCRA characteristics) to over $800 million per year (for an unlikely scenario that approximates a full RCRA Subtitle C regulatory approach, emphasizing cap and liner containment for all wastes considered hazardous under the current criteria, plus cyanide and acid formation wastes). About 60 percent of the total projected annualized cost at active facilities can be attributed to the management of waste accumulated from past production. Those segments with no hazardous wastes (e.g., iron) would incur no costs. Within a segment, incremental costs would vary greatly from facility to facility, depending on current requirements of state laws, ore grade, geography, past waste accumulation, percentage of waste with hazardous characteristics, and other factors.

RECOMMENDATIONS

Section 8002(f) of RCRA requires EPA to conduct a study of the adverse effects of mining waste and to provide "recommendations for Federal...actions concerning such effects." Based on our findings from this study, we make several preliminary recommendations for those wastes and industry segments included in the scope of the study. The recommendations are subject to change based on continuing consultations with the Department of the Interior (DOI) and new information submitted through the public hearings and comments on this report. Pursuant to the process outlined in RCRA §3001(b)(3)(C), we will announce our specific regulatory determination within 6 months after submitting this report to Congress.

First, EPA is concerned with those wastes that have the hazardous characteristics of corrosivity or EP toxicity under current RCRA regulations. EPA intends to investigate those waste streams. During the course of this investigation, EPA will assess more rigorously the need for and nature of regulatory controls. This will require further evaluation of the human health and environmental exposures mining wastes could present. EPA will assess the risks posed by mining waste sites and alternative control options. The Agency will perform additional waste sampling and analysis, additional ground-water or surface water monitoring and analysis, and additional analysis of the feasibility and cost-effectiveness of various control technologies.

If the Agency determines through the public comments, consultation with DOI and other interested parties, and its own analysis, that a regulatory strategy is necessary, a broad range of management control options consistent with protecting human health and the environment will be considered and evaluated. Moreover, in accordance with Section 3004(x), EPA will take into account "the special characteristics of such waste, the practical difficulties associated with implementation of such requirements and site specific characteristics...," and will comply with the requirements of Executive Orders 12291 and 12498 and the Regulatory Flexibility Act.

Second, EPA will continue gathering information on those waste streams that our study indicates may meet EPA's criteria for listing as hazardous wastes requiring regulation--dump leach waste, because of its high metal concentrations and low pH, and wastes containing cyanides. Although these waste streams are potential candidates for listing as hazardous wastes, we need to gather additional information similar to the information gathered for the rulemaking for corrosive and EP toxic wastes. When we have gathered sufficient information, we will announce our decision as to whether to initiate a formal rulemaking. If the Agency finds it necessary to list any of these wastes, we will also develop appropriate management standards in the same manner as we did those developed for corrosive and EP toxic wastes.

Finally, EPA will continue to study radioactive waste and waste with the potential to form sulfuric acid. The Agency is concerned that radioactive wastes and wastes with the potential for forming acid may pose a threat to human health and the environment, but we do not have enough information to conclude that they do. We will continue to gather information to determine whether these wastes should be regulated. If EPA finds that it is necessary to regulate these wastes, the Agency will develop the appropriate measures of hazard and the appropriate waste management standards.

SECTION 1

INTRODUCTION

This report is required by Sections 8002(f) and (p) of the Resource Conservation and Recovery Act (RCRA), which directs the Environmental Protection Agency (EPA) to perform studies of wastes generated in the mining, beneficiation, and processing of ores and minerals and to report the results of these studies to Congress. This report is based on literature reviews and contractor studies, including numerous analytical testing results on the wastes. EPA's RCRA Docket contains copies of the source materials that the Agency used in preparing this report.

Because Congress has amended the Act several times in ways that changed the requirements for mining wastes, and because EPA regulations continue to evolve both in response to legislation and as EPA collects additional information, a brief legislative and regulatory history provides a useful context for this Report to Congress.

When first enacted in 1976 (P.L. 94-580), RCRA contained a broad definition of solid waste that included "solid, liquid, semi-solid, or contained gaseous material resulting from...mining...operations." [emphasis added] (Section 1004(27)).

Section 8002(f) of the original Act directed EPA to conduct a

> detailed and comprehensive study on the adverse effects of solid wastes from active and abandoned surface and underground mines on the environment, including, but not limited to, the effects of such wastes on humans, water, air, health, welfare, and natural resources, and on the adequacy of means and measures currently employed by the mining industry, Government agencies, and others to dispose of and utilize such solid wastes to prevent or substantially mitigate such adverse effects.

The study was to include an analysis of:

1. The sources and volume of discarded material generated per year from mining;
2. Present disposal practices;
3. Potential danger to human health and the environment from surface runoff of leachate and air pollution by dust;
4. Alternatives to current disposal methods;
5. The cost of those alternatives in terms of the impact on mine product costs; and
6. Potential for use of discarded material as a secondary source of the mine product.

The Act did not specify a date for the completion of this study.

On December 18, 1978, EPA proposed regulations to implement Subtitle C of RCRA, including rules for identifying and listing hazardous wastes and for managing these wastes. Based on the language in the House Committee Report accompanying the House Bill, which was the predecessor to the Act, EPA specifically excluded as a hazardous waste "overburden resulting from mining operations and intended for return to the mine site" unless the overburden was specifically listed. The Agency proposed to list waste rock and overburden from uranium mining and overburden and slimes from phosphate surface mining because of concern about their radioactivity. The proposal also considered any other mining wastes that were ignitable, corrosive, reactive, or EP toxic as hazardous waste.

In addition, the proposal included distinct management standards for "special wastes," which "occur in very large volumes" and for which "the potential hazards...are relatively low" (43 FR 58992, December 18, 1978). The Agency proposed less stringent standards for these wastes than for other hazardous wastes, pending the development of additional information and a subsequent planned rulemaking. Certain mining wastes were among the special wastes. They included phosphate mining, beneficiation, and processing wastes; uranium mining waste; and other mining waste that was ignitable, corrosive, reactive, or EP toxic.

On May 19, 1980, EPA promulgated interim final regulations implementing Subtitle C of RCRA. The Agency retained the exclusion for overburden that was returned to the mine site; however, the Agency dropped the two proposed listings, because the regulations "eliminated the part of the proposed exemption that would allow exempted overburden to be brought within RCRA jurisdiction through specific listing as a hazardous waste" (45 FR 33100, May 19, 1980). EPA also promulgated interim final listings for three specific mining waste streams: (1) flotation tailings from selective flotation from mineral metals recovery operations, (2) cyanidation wastewater treatment tailings pond sediment from mineral metals recovery operations, and (3) spent cyanide bath solutions from mineral metals recovery operations. Before the first of these listings became effective, however, EPA withdrew this listing based on technical comments from the regulated community.

These promulgated standards did not have distinct and less stringent management standards for mining wastes. Between the time of the proposal and the promulgation of the interim final rule, EPA modified the EP toxic and corrosivity criteria for hazardous wastes, and the Agency therefore anticipated that a smaller quantity of mining wastes would be classified as hazardous based on results of tests for these two characteristics. However, EPA judged that wastes so classified would clearly exhibit sufficient toxicity to be of concern. "Thus the concern over the inapplicability of the proposed regulations to hazardous special wastes, due to the potentially large volume and low level of hazard of these wastes, is not a valid concern in the final regulations" (45 FR 33174, May 19, 1980). The preamble also noted that there was no current provision that would permit deferring the regulation of mining wastes until the results of the Section 8002(f) study were available. EPA did point out, however, that Congress was considering legislation that would amend RCRA to require deferral until the study was complete.

Congress then amended RCRA in the Solid Waste Disposal Act of 1980 (P.L. 96-482), enacted on October 21, 1980. Among other things, the amendments prohibited EPA from regulating solid waste from the "extraction, beneficiation, and processing of ores and minerals, including phosphate rock and overburden from the mining of uranium ore" as hazardous wastes under Subtitle C of RCRA until at least 6 months after the Agency completed and submitted to Congress the studies required by Section 8002(f) and by a new section, 8002(p).

Section 8002(p) requires EPA to perform a comprehensive study on the disposal, and utilization of solid waste from the extraction, beneficiation, and processing of ores and minerals, including phosphate rock and overburden from uranium mining. This new study, to be conducted in conjunction with the study of mining wastes required by Section 8002(f), mandated an analysis of:

1. The source and volumes of such materials generated per year;
2. Present disposal and utilization practices;
3. Potential danger, if any, to human health and the environment from the disposal and reuse of such materials;
4. Documented cases in which danger to human health or the environment has been proven;

5. Alternatives to current disposal methods;

6. The costs of such alternatives;

7. The impact of these alternatives on the use of phosphate rock and uranium ore, and other natural resources; and

8. The current and potential utilization of such materials.

The amendments also required the Administrator, "after public hearings and opportunity for comment, either to determine to promulgate regulations" for mining wastes or "to determine that such regulations are unwarranted." These determinations must be published in the Federal Register.

Finally, the amendments specified that EPA could control radiation exposures caused by mining wastes under RCRA. Section 3001(b)(3)(B)(iii) authorized the Administrator to

> prescribe regulations...to prevent radiation exposure which presents an unreasonable risk to human health from the use in construction or land reclamation (with or without revegetation) of (I) solid waste from the extraction, beneficiation, and processing of phosphate rock or (II) overburden from the mining of uranium ore.

On November 19, 1980, EPA published an interim final rule to implement the 1980 RCRA Amendments. Specificially, EPA excluded from regulation under Subtitle C of the Resource Conservation and Recovery Act "...solid waste from the extraction, beneficiation and processing of ores and minerals (including coal), including phosphate rock and overburden from the mining of uranium ore" (45 Fed. Reg. 76618, codifield at 40 CFR 261.4(b)(7)). The Agency interpreted the scope of the exclusion very broadly:

> Until the Agency takes further rulemaking action on this matter, it will interpret the language of today's amendments, with respect to the mining and mineral processing waste exclusion, to include solid waste from the exploration, mining, milling, smelting and refining of ores and

> minerals. This exclusion does not, however, apply to solid wastes, such as spent solvents, pesticide wastes, and discarded commercial chemical products, that are not uniquely associated with these mining and allied processing operations (45 FR 76619, November 19, 1980).

EPA solicited public comment on its interpretation to assist in determining the appropriate scope of the statutory exclusions.

> In particular, EPA questions whether Congress intended to exclude (1) wastes generated in the smelting, refining and other processing of ores and minerals that are further removed from the mining and beneficiation of such ores and minerals, (2) wastes generated during exploration for mineral deposits, and (3) wastewater treatment and air emission control sludges generated by the mining and mineral processing industry. EPA specifically seeks comment on whether such wastes should be part of the exclusion. EPA also seeks comment on how it might distinguish between excluded and non-excluded solid wastes (45 FR 76619, November 19, 1980).

The Hazardous and Solid Waste Amendments of 1984, enacted in November of that year as P.L. 98-616, represent the culmination of the House and Senate reauthorization hearings begun in early 1983. Of chief concern to the mining industry are amendments that provide EPA flexibility in applying bans on land disposal and certain requirements for obtaining permits under Subtitle C of RCRA to the mining industry.

The amended statute provides, under Section 3004(x), that if mining wastes become subject to regulation as hazardous wastes under Subtitle C, the Administrator of EPA, in promulgating regulations, is authorized to modify the requirements of subsections (c), (d), (e), (f), (g), (o), and (u) of Section 3004 and subsection 3005(j), which relate to:

1. Liquids in landfills,
2. Prohibitions on land disposal,
3. Solvents and dioxins,
4. Disposal into deep injection wells,

5. Additional land disposal prohibition determinations,
6. Minimum technological requirements,
7. Continuing releases at permitted facilities, and
8. Interim status surface impoundments.

The Administrator is authorized to take into account the special characteristics of mining and beneficiation wastes, "the practical difficulties associated with implementation of such requirements, and site-specific characteristics, including, but not limited to, the climate, geology, hydrology, and soil chemistry at the site, so long as such modified requirements assure protection of human health and the environment."

The Conference Report accompanying H.R. 2867 (which in its final amended form was passed by both Houses of Congress as P.L. 98-616) provides clarification:

> This Amendment recognizes that even if some of the special study wastes [which include mining wastes as specified in Sections 8002 (f) and (p)] are determined to be hazardous it may not be necessary or appropriate because of their special characteristics and other factors, to subject such wastes to the same requirements that are applicable to other hazardous wastes, and that protection of human health and the environment does not necessarily imply the uniform application of requirements developed for disposal of other hazardous wastes. The authority delegated to the Administrator under this section is both waste-specific and requirement-specific. The Administrator could also exercise the authority to modify requirements for different classes of wastes. Should these wastes become subject to the requirements of Section 3005 (j), relating to the retrofit of surface impoundments, the Administrator could modify such requirements so that they are not identical to the requirements that are applied to new surface impoundments containing such wastes. It is expected that before any of these wastes become subject to regulations under subtitle C, the Administrator will determine whether the requirements of Section 3004 (c), (d), (e), (f), (g), (o), and (u), and Section 3005(j) should be modified [H.R. Report 98-1133, pp. 93-94, October 3, 1984].

On October 2, 1985, EPA proposed (50 Fed. Reg. 401292) to reinterpret the scope of the mining waste exclusion as it applies to processing wastes, leaving within it only large-volume processing wastes, such as slag from primary metal smelters and elemental phosphorus plants, red and brown muds from bauxite refineries, and phosphogypsum from phosphoric acid plants. Those other wastes from processing ores and minerals that are hazardous would be brought under full Subtitle C regulation after the promulgation of the reinterpretation, and would therefore not be included in the scope of a subsequent Report to Congress on processing wastes. The large-volume processing wastes that remain within the exclusion would be studied and a Report to Congress prepared to complete EPA's response to the RCRA Section 8002(p) mandate.

Thus, EPA must submit a Report to Congress under RCRA Sections 8002(f) and (p) and then publish its findings in the Federal Register before any waste covered by the mining exclusion can be regulated under Subtitle C of RCRA. No such restrictions, however, apply to wastes not included within the scope of the exclusion.

1.1 SCOPE

This report addresses waste from the mining and beneficiation of metallic ores, with special emphasis on copper, gold, iron, lead, molybdenum, silver, and zinc; uranium overburden; and the nonmetals asbestos, phosphate rock, and oil shales. (Appendix A to this report addresses wastes from the mining and beneficiation of oil shales.) EPA selected the mining industry segments to be covered in this report on the following basis. First, the Agency excluded wastes that are the primary responsibility of other regulatory agencies. Thus, this report does not address uranium mill tailings or the mining and beneficiation of coal. The Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA) (P.L. 95-604) requires proper disposal of "residual radioactive material," including mill tailings and residual stocks of unprocessed ores or low-grade materials. UMTRCA directed EPA to prepare a Report to Congress on uranium mill tailings, and the Agency has done so.[1] Under UMTRCA, EPA determines "standards of general application," and the Nuclear Regulatory Commission writes the implementing regulations and enforces them for active mills. Uranium mill tailings are defined as "byproduct material" by the Atomic Energy Act and, as such, do not constitute a "solid waste" as defined by RCRA Section 1004(27). Therefore, they are not subject to RCRA requirements.

The Surface Mining Control and Reclamation Act of 1977 (SMCRA) (P.L. 95-87) applies to surface coal mining reclamation activities. Under RCRA, the Administrator of EPA must review any regulations under SMCRA that are applicable to coal mining wastes and overburden. However, the Secretary of the Interior, with concurrence from the Administrator of EPA, is responsible for promulgating regulations that effectuate the purposes of Subtitle C of RCRA with respect to "coal mining wastes or overburden for which a surface coal mining and reclamation permit is issued or approved under the Surface Mining Control and Reclamation Act of 1977."

The Agency also excluded from the scope of this report wastes generated in the processing of ores or minerals. EPA will address large-volume wastes (such as slag and phosphogypsum) generated by these processes in a subsequent report. EPA will also evaluate other nonmetal mining wastes (in addition to asbestos and phosphate) and wastes from inactive or abandoned mines at a later time.

1.2 CONTENTS

This report consists of seven sections and four appendices. The following paragraphs briefly discuss each of the remaining sections of the report.

Section 2, OVERVIEW OF THE NONFUEL MINING INDUSTRY,[2] presents a summary of the mining and beneficiation of ores and minerals and provides information on the number of mines, their geographic distribution, and the quantity of waste generated in mining and beneficiation.

Section 3, MANAGEMENT PRACTICES FOR MINING WASTES, provides an overview of the mining waste management process and discusses specific waste management practices and mitigative measures for the land disposal of mining waste. For some segments of the industry, the section provides information on the proportion of mine facilities that currently practice these mitigative measures.

Section 4, POTENTIAL DANGER TO HUMAN HEALTH AND THE ENVIRONMENT, presents information on the characteristics of the wastes that pose a potential threat to human health and the environment. It estimates how much mining industry waste would fail current RCRA hazardous waste characteristics, and how much would be hazardous under an augmented set of characteristics. It then provides the results of EPA's monitoring of ground water at selected sites. It also discusses the structural stability of impoundments used to manage mining waste. Next, it presents damage cases. Finally, it describes how risk analysis could be used to quantify the effects that current and alternative practices have on human health and the environment.

Section 5, THE ECONOMIC COST OF POTENTIAL RCRA WASTE MANAGEMENT, first presents the methodology EPA used to determine the potential cost of regulating mining wastes under RCRA, using four different regulatory scenarios and two different sets of hazard criteria. The section then presents the results of the analysis in terms of total potential costs, the potential costs to various mining sectors, and the potential costs to the affected mines.

Section 6, CONCLUSIONS AND RECOMMENDATIONS, summarizes the conclusions reached in the other sections of the report and presents EPA's recommendations.

Section 7, SELECTED BIBLIOGRAPHY, lists the sources that were used in this report as well as some references that contain valuable information related to mining waste.

This report also contains four appendices:

- Appendix A, SUMMARY OF MAJOR WASTES FROM THE MINING AND PROCESSING OF OIL SHALES, summarizes a report on high-volume wastes generated by the mining and processing of oil shales. This information was not included in this Report to Congress because the United States oil shale industry is not yet operating on a commercial scale. The entire oil shale report is available in the EPA docket.

- Appendix B, METHODOLOGY, describes the methdology used by EPA to assess current industry waste management practices and to estimate the amount of hazardous mining waste generated annually.

- Appendix C, SELECTED CRITERIA ANALYZED FOR TOXIC EFFECTS, contains tables comparing levels of metals measured by the EP toxicity test allowed by various EPA standards and criteria; tables on arsenic, cadmium, chromium, lead, mercury, selenium, and cyanide toxicity to aquatic biota are also included. In addition, this appendix summarizes radiation effects and effects of asbestos exposure on various biological species, and the effects of decreasing pH on fish.

- Appendix D, GLOSSARY, provides definitions of mining-related and other technical terms referred to in the text.

SECTION 1 FOOTNOTES

1 US EPA 1983a.

2 For the purposes of this report, the nonfuel mining industry is defined as including uranium although processed uranium may be used as fuel.

SECTION 2

OVERVIEW OF THE NONFUEL MINING INDUSTRY

The nonfuel mining industry is an integral part of our economy. It provides a diversity of products, including the lead used in storage batteries, ammunition, and pigments; copper for electrical equipment and supplies; iron for the construction and transportation industries; zinc for galvanizing and other uses; silver for photographic materials; gold for electronic equipment, jewelry, and medicinal use; and the uranium used by electric utilities. This sector also produces nonmetallic minerals such as asbestos for use in insulating materials and phosphates used to produce industrial chemicals and fertilizers.[1] The total metal ore production in the United States was worth more than $5.8 billion, and the total value of raw nonfuel minerals was more than $21 billion in 1983.[2] This value accounted for 1 percent of the Gross National Product (GNP), while products made from these raw materials account for approximately 9 percent of the GNP annually.[3]

2.1 NONFUEL MINING SEGMENTS

There were 580 metal mines and 12,117 nonmetal mines active in 1980 (the most recent year for which complete data are available from the U.S. Bureau of Mines).[4] The number of active mines varies from year to year, depending on factors such as the level of U.S. economic activity, the costs of production in the mining industry, the demand for products derived from nonfuel minerals, and prices in international markets. In general, the number of mines in operation has decreased over the past several years; however, a reasonable estimate for 1983 indicates that between 400 and 500 metal mines operated in the segments covered here. Table 2-1 lists the number of active nonfuel mines in 1980, 1981, and 1982 for the mining industry segments covered in this report: all metal mines, except gold placer operations, appear in the metals category, and all asbestos and phosphate mines appear in the nonmetals category. The metal mining segments include copper, gold, iron ore, lead, molybdenum, silver, uranium, zinc, and a group of "other" metals. The metals in the "other" category have been grouped in order to avoid disclosing confidential business information; they include antimony, bauxite, beryllium, mercury, nickel, the rare earth metals, titanium, and vanadium. Because domestic tin and manganiferous ore mines have been minor sources of ore since 1982, these segments are not covered in this report. Platinum also is not covered in this report because no platinum mines have been active since 1982.

Although mines are classified on the basis of their predominant product, they may also produce large quantities of other materials as coproducts. For example, in 1978, U.S. zinc mines produced 72 percent of all zinc; 100 percent of all cadmium, germanium, indium, and thallium; and 3.1, 4.1, and 6.1 percent of all gold, silver, and lead mined in the United States, respectively. In the same year, copper mines produced over 30 percent of the silver, 35 percent of the gold, and 100 percent of the rhenium, selenium, palladium, tellurium, and platinum mined in this country.[5] Thus, a copper mine may also produce gold and silver as coproducts. Table 2-2 summarizes the products and coproducts for selected metal mining segments.

In most mining segments, a few large mines produce most of the product. Table 2-3 shows the number of mines in each segment, categorized by volume of material handled. This volume includes the amount of earth and rock that must be removed to reach the ore. About half of all U.S. metal mines active in 1982 were small, handling less than 10,000 tons of material each. These 213

Table 2-1 Number of Active Mines in the Industry Segments Covered in This Report in 1980, 1981, and 1982[a]

Mining industry segment	Number of mines 1980	Number of mines 1981	Number of mines 1982
Metals:			
Bauxite (aluminum)	10	10	8
Copper	39	44	32
Gold[b]	44	107	101
Iron ore	35	31	26
Lead	33	29	17
Silver	43	75	63
Titanium	5	5	5
Tungsten	29	29	23
Uranium	265	195	128
Zinc	20	17	14
Other metals[c]	21	18	21
Subtotal	544	560	438
Nonmetals:			
Asbestos	4	4	3
Phosphate rock	44	43	33
Subtotal	48	47	36
TOTAL	592	607	474

[a] Excludes wells, ponds, and pumping operations.

[b] Excludes placer operations.

[c] Includes antimony, beryllium, mercury, molybdenum, nickel, platinum, rare-earth metals, and vanadium.

Source: Adapted from BOM 1981a, BOM 1982, and BOM 1983.

Table 2-2 Product As a Percentage of Total Output for Selected U.S. Metal Mines in 1978

Primary mine product	Product or Coproduct				
	Copper	Gold	Lead	Silver	Zinc
Copper	98.8	36.7	--[b]	31.7	1.3
Gold	--[b]	55.6	--[b]	1.7	--[b]
Lead	0.8	0.1	90.3	8.7	25
Silver	0.3	4.1	3.4	53.7	0.9
Zinc	0.1	3.1	6.1	4.1	72
Total[a]	100.0	99.6	99.8	99.9	99.2

[a] Totals may not equal 100 percent due to rounding.

[b] Indicates less than 0.5 percent.

Source: Adapted from BOM 1981a.

Table 2-3 Mines in the Industry Segments Covered in this Report in 1982, by Volume of Material Handled[a,b]

Mining industry segment	Total number of mines	Less than 1,000 tons	1,000 to 10,000 tons	10,000 to 100,000 tons	100,000 to 1,000,000 tons	1,000,000 to 10,000,000 tons	More than 10,000,000 tons
Metals:							
Bauxite (aluminum)	8	--	1	5	2	--	--
Copper	32	3	1	5	1	15	7
Gold[c]	101	41	28	11	14	6	1
Iron ore	26	--	2	4	6	8	6
Lead	17	7	1	--	2	7	--
Silver	63	32	14	6	10	1	--
Titanium	5	--	--	--	1	4	--
Tungsten	23	18	2	2	1	--	--
Uranium	128	16	34	52	24	2	--
Zinc	14	--	1	2	9	2	--
Other metals[d]	21	5	7	2	2	5	--
Subtotal	438	122	91	89	72	50	14
Nonmetals:							
Asbestos	3	--	--	3	--	--	--
Phosphate rock	33	--	1	--	4	23	5
Subtotal	36	--	1	3	4	23	5
TOTAL	474	122	92	92	76	73	19

[a] Includes product and waste, but excludes wells, ponds, and pumping operations.
[b] These data are reported in short tons; one short ton equals 1.1 metric tons.
[c] Excludes placer operations.
[d] Includes antimony, beryllium, mercury, molybdenum, nickel, rare-earth metals, and vanadium.

Source: BOM 1981a.

small mines handled only 10 percent of the material handled by the 14 largest mines.

2.2 GEOGRAPHIC DISTRIBUTION OF MINES

Because ores occur only in certain geologic formations, most of the mining in each industry segment is concentrated in a few locations. Copper mining is centered in three states: Arizona, Utah, and New Mexico. Other states where copper is mined as a coproduct of silver, zinc, and lead production are Montana, Tennessee, and Missouri, respectively. Some copper mines and mills are close to large cities (Tucson and Salt Lake City), but most active operations are in sparsely populated (four people per square kilometer, compared with a national average of 25 people per square kilometer) parts of Arizona.

Nevada, South Dakota, and Montana were responsible for 85 percent of the primary gold production in 1983 (excluding gold produced by Alaskan placer operations). Other primary gold-producing states are California, Colorado, Idaho, New Mexico, and Utah. Gold is also produced as a coproduct of silver and copper mining in Utah, Nevada, and Arizona. Placer mines in Alaska and gold heap leaching operations in Nevada are located in areas far removed from population centers.

Almost all iron ore is mined in Minnesota and Michigan, although Texas, Missouri, Utah, Wyoming, and California combined are responsible for approximately 5 percent of all iron ore production. Primary lead production in the United States is confined to Missouri, where lead mining is concentrated in the Mark Twain National Forest (the average population density in the southeastern part of the state is five people per square kilometer). Lead is also recovered as a coproduct from some western mining operations. Colorado is the primary molybdenum-producing state. Although silver is mined in many states, its production as a primary metal is concentrated in sparsely populated areas of Idaho, Montana, Nevada, and Utah. Primary silver production accounted for 70 percent of U.S. silver output in 1983, an increase of 54 percent since 1978 (see Table 2-2). The remainder was produced as a coproduct of copper, gold, lead, and other metals mining activities.

Uranium mining is concentrated in sparsely populated parts of New Mexico, Wyoming, Colorado, and Utah. Zinc is produced in Tennessee, New York, Missouri, New Jersey, Idaho, and Colorado; Missouri produces 21 percent of all U.S. zinc as a coproduct of lead production. Zinc is also a coproduct of silver production. Zinc mining in Tennessee and New York is located in moderately populated areas (45 people per square kilometer in Tennessee and 16 people per square kilometer in New York). The largest Tennessee zinc mining district is 50 kilometers from Knoxville.

The mining of metals in the other metals category is generally restricted to the metal ore-producing states mentioned above. Additionally, California produces tungsten and rare earth metals, and Arkansas produces bauxite for metallurgical uses.

Asbestos mining is restricted to California and Vermont. The asbestos mine in Vermont and one of the mines in California are in areas of moderate population density. Phosphate mining is concentrated in Florida, North Carolina, and Idaho. In Idaho, phosphate mining occurs in a sparsely populated area; but in Florida, most phosphate operations are about 65 kilometers east of Tampa, in an area with a population density of 68 people per square kilometer. Table 2-4 summarizes the number of operating mines and percentage of 1983 production in each state, arranged by EPA region, for the nonfuel mining segments covered in this report. Note that for some products, a few mines are responsible for the majority of all primary production. For

Table 2-4 Active Mines and Percentage of Production by State[a] in 1983

States arranged by EPA region	Copper	Gold[b]	Iron ore	Lead	Molybdenum	Silver	Uranium	Zinc	Asbestos	Phosphate
I										
Vermont	--	--	--	--	--	--	--	--	1(25)	--
II										
New Jersey	--	--	--	--	--	--	--	1(8)	--	--
New York	--	--	--	--	--	--	--	2(27)		
III										
Pennsylvania	--	--	--	--	--	--	--	1(8)	--	--
IV										
Florida	--	--	--	--	--	--	--	--	--	20(74)
N. Carolina	--	--	--	--	--	--	--	--	--	1(11)
Tennessee	1(1)	--	--	--	--	--	--	7(51)	--	4(3)
V										
Michigan	--	--	2(25)	--	--	--	--	--	--	--
Minnesota	--	--	9(70)	--	--	--	--	--	--	--
VI										
N. Mexico	2(11)	6(3)	--	--	--	5(1)	20(25)	--	--	--
Texas	--	--	2(1)	--	--	--	6(5)	--	--	--
VII										
Missouri	--	--	1(2)	7(100)	--	--	--	--	--	--
VIII										
Colorado	--	20(4)	--	--	2(100)	5(6)	28(15)	1(6)		
Montana	1(3)	16(10)	--	--	--	9(17)	--	--	--	1(1)
S. Dakota	--	1(19)	--	--	--	--	--	--	--	--
Utah	1(17)	1(2)	3(1)	--	--	3(8)	23(13)	--	--	1(1)
Wyoming	--	--	2(1)	--	--	--	22(40)	--	--	--

Table 2-4 (Continued)[a]

States arranged by EPA region	Copper	Gold[b]	Iron ore	Lead	Molybdenum	Silver	Uranium	Zinc	Asbestos	Phosphate
IX										
Arizona	20(68)	4(< 1)	--	--	--	7(< 1)	--	--	--	--
California	--	16(2)	1(4)	--	--	1(1)	--	--	2(75)	--
Nevada	--	45(56)	--	--	--	10(14)	--	--	--	--
X										
Alaska	--	--	--	--	--	--	--	--	--	--
Idaho	--	8(3)	--	--	--	11(55)	--	--	--	5(11)
Washington	--	--	--	--	--	--	1(3)	--	--	--
TOTAL NUMBER OF MINES	25(100)	117[b](100)	20(100)	7(100)	2[c](100)	51(100)	100(100)	12(100)	3(100)	32(100)

[a] Numbers in parentheses represent the percentage of primary product production. Percentages may not add to 100 because of rounding.

[b] Excludes placer operations.

[c] 1982 data.

Source: Charles River Associates 1985, based on data from BOM.

example, two mines produce 75 percent of all U.S. asbestos, nine mines produce 70 percent of all iron ore, and seven mines are responsible for all lead ore production.

2.3 MINING AND BENEFICIATION WASTES

In the nonfuel mining industry, the valuable portion of the crude ore is a small fraction of the total volume of material that must be handled to obtain it (Table 2-5). For example, over 6,900 units of material must be handled to obtain one marketable unit of uranium. The high ratio of "material handled" to "marketable product" is due primarily to the low percentage of metal in the ore and to the mining methods and processes that must be employed. As shown in Table 2-5, no metal exceeds 5 percent of the crude ore in which it is embedded, except iron. Aluminum in metallurgical bauxite presents a similar picture. As high-grade ore reserves continue to dwindle, these percentages are likely to become even smaller. The fact that the materials handled consist largely of waste or unusable materials distinguishes these mining industry segments from many other process industries where waste materials make up a relatively small portion of the materials processed to produce a final product.

Several stages in the production of valuable products from minerals and ores require the handling of large volumes of material, much of which is waste. Overburden and waste rock must be removed to expose the ore. The ores are then extracted (mined) and then transported to a nearby mill, where they are beneficiated (concentrated or dressed). Mining and beneficiation processes generate four categories of large-volume waste: mine waste, tailings, dump and heap leach waste, and mine water.

Mining includes a variety of surface and underground procedures. Surface

Table 2-5 Ratio of Material Handled to Units of Marketable Metal and Estimated Percentage of Metals in Ore

Mining industry segment	Ratio of material handled to units of marketable metal[a,b]	Typical percentage of metal in ore[c]
Copper	420:1	0.6
Gold	350,000:1	0.0004
Iron ore	6:1	33.0
Lead	19:1	5.0
Mercury	NA	0.5
Molybdenum	NA	0.2
Silver	7,500:1	0.03
Tungsten	NA	0.5
Uranium	6900:1	0.15
Zinc	27:1	3.7

NA indicates not available.

[a] Excludes material from development and exploration activities.

Source: [b]BOM 1983, and [c] estimated by Charles River Associates 1985.

mining methods include quarrying, and open-pit, open-cut, open-cast, dredging, and strip mining. Underground mining creates adits (horizontal passages) or shafts by room-and-pillar, block caving, timbered stope, open stope, and other methods. Hydrometallurgical processes include heap, dump, vat, and in situ leach mehods. (See Appendix D, Glossary, for a description of mining methods.) The vast majority of nonfuel ores are mined on the surface. Only antimony, lead, and zinc mining are solely underground operations. As shown in Table 2-6, the industry segments that employ both methods handled more ore in surface mines than in below-ground mines (with the exception of silver) in 1982.

Surface mining generates more waste than underground mining.[6] Table 2-7 compares the waste and crude ore handled by the industry segments that mine both above and below ground. (Reliable data were not available for iron ore.) As shown, the volume of waste as a percentage of the total amount of crude ore ranges from 9 to 27 percent for underground mines. In surface mining, the amount of waste ranges from 2 to 10 times the total volume of crude ore. Gold surface mining creates nearly 12 times as much waste per unit of ore as underground gold mining; silver generates 59 times as much. All mining methods used by the industry segments covered in this report generate mine waste. It should be emphasized, though, that the typical percentage of metal in an ore (excluding overburden and waste rock) is usually very low (from a few percent to a fraction of a percent).

Mine waste is the soil or rock that mining operations generate during the process of gaining access to an ore or mineral body, and includes the overburden (consolidated or unconsolidated material overlying the mined area) from surface mines, underground mine development rock (rock removed while sinking shafts, accessing, or exploiting the ore body), and other waste rock,

Table 2-6 Percentage of Crude Ore Handled at Surface and Underground Mines in 1982, by Commodity

Mining industry segment	Surface mines	Underground mines
Metals:		
Antimony	--	100.0
Bauxite (aluminum)	100.0	--
Beryllium	100.0	--
Copper	87.6	12.4
Gold[a]	92.0	8.0
Iron ore	98.9	1.1
Lead	--	100.0
Mercury	100.0	--
Molybdenum	100.0[b]	W
Nickel	100.0	--
Rare earth metals	100.0	--
Silver	36.0	64.0
Titanium	100.0	--
Tungsten	W	100.0[c]
Uranium	68.8	31.2
Vanadium	100.0	--
Zinc	--	100.0
Average percent mined	69.7	30.4
Nonmetals:		
Asbestos	100.0	--
Phosphate rock	100.0[b]	--
Average percent mined	100.0	0
Average percent mined, metals and nonmetals	72.8	27.2

W indicates information withheld by Bureau of Mines to protect confidential business information.

[a] Excludes placer operations.

[b] Includes underground operations; the Bureau of Mines does not publish these data separately.

[c] Includes surface operations; the Bureau of Mines does not publish these data separately.

Source: Adapted from BOM 1983.

Table 2-7 Material Handled at Surface and Underground Mines in 1982, for Selected Industry Segments (in thousands of metric tons)

Mining industry segment	Surface			Underground		
	Crude ore	Waste	Waste/ crude ore ratio	Crude ore	Waste	Waste/ crude ore ratio
Copper	156,004	321,985	2.06	22,040	1,968	0.09
Gold	21,768	48,797	2.24	1,896	369	0.19
Silver	2,186	19,319	8.84	3,891	584	0.15
Uranium	6,848	72,197	10.54	3,111	848	0.27

Source: Adapted from BOM 1983.

including the rock interbedded with the ore or mineral body. The particle size of mine waste ranges from small clay particles (0.002 mm diameter) to boulders (0.3 m diameter). Mine waste piles cover areas ranging from 2 to 240 hectares, with a mean area of 51 hectares (1 hectare equals 2.471 acres), according to a U.S. Bureau of Mines (BOM) survey of 456 waste piles in the copper, lead, zinc, gold, silver, and phosphate industry segments.[7]

After the ore is mined, the first step in beneficiation is generally grinding and crushing. The crushed ores are then concentrated to free the valuable mineral and metal particles (termed values) from the matrix of less valuable rock (called gangue). Beneficiation processes include physical/chemical separation techniques such as gravity concentration, magnetic separation, electrostatic separation, flotation, ion exchange, solvent extraction, electrowinning, precipitation, and amalgamation.[8] The choice of beneficiation process depends on properties of the metal or mineral ore and the gangue, the properties of other minerals or metals in the same ore, and the relative costs of alternative methods. All processes generate tailings, another type of waste.

Tailings are the waste materials remaining after physical or chemical beneficiation operations remove the valuable constituents from the ore. Tailings generally leave the mill as a slurry, consisting of 50 to 70 percent (by weight) liquid mill effluent and 30 to 50 percent solids (clay, silt, and sand-sized particles).

More than half of all mine tailings are disposed of in tailings ponds. Use of tailings ponds is the primary method by which wastewater is treated in the metals ore mining segment. Also, settling ponds are typically used at mineral mining and processing operations. Pond size and design vary by industry segment and mine location. Some copper tailings ponds in the southwest cover 240 to 400 hectares (one exceeds 2,000 hectares), while some small lead/zinc tailings ponds cover less than 1 hectare. Based on a BOM survey of 145 tailings ponds in the copper, lead, zinc, gold, silver, and phosphate industries, the average size of these ponds is approximately 200 hectares.[9] Many facilities use several ponds in series, which improves treatment efficiency. Multiple-pond systems offer other advantages as well, as the tailings themselves are often used to construct dams and dikes.

Technological advances since the turn of the century have made it economically feasible to beneficiate ore taken from lower-grade ore deposits (i.e., those with a much lower material-to-waste ratio).[10] For example, froth flotation beneficiation processes have had a tremendous effect on mine production and on the amount and type of mine waste generated. Not only have these advances increased mining production, but the volume of waste generated also has risen dramatically. The tailings from froth flotation operations are generally alkaline, because the froth flotation process is most efficient at a higher pH. The metals in the alkaline tailing solids are therefore often immobile, unless the conditions in the solids change over time.

Dump leaching, heap leaching and in situ leaching are other processes used to extract metals from low-grade ore. In dump leaching, the material to be leached is placed directly on the ground. Acid is applied, generally by spraying, although many sulfide ores will generate acid during wetting. As the liquid percolates through the ore, it leaches out metals, a process that may take years or decades. The leachate, "pregnant" with the valuable metals, is collected at the base of the pile and subjected to further processing to recover the metal. Dump leach piles often cover hundreds of hectares, rise to 60 meters or more, and contain tens of millions of metric tons of low-grade ore (overburden), which becomes waste after leaching. The dump leach site is often selected to take advantage of impermeable surfaces and to utilize the natural slope of ridges and valleys for the collection of pregnant leach solutions. Loss of leach solution is kept to a minimum in order to maximize metal recovery.

Heap leaching operations are much smaller than dump leach operations, generally employ a relatively impermeable pad under the leach material to maximize recovery of the leachate, and usually take place over a period of months rather than years. Heap leaching is generally used for ores of higher grade or value. For gold ore, a cyanide solution is used as a leaching solution, rather than acid. When leaching no longer produces economically attractive quantities of valuable metals, and the sites are no longer in use, the spent ore is often left in place or nearby without further treatment.

In situ leaching is employed in shattered or broken ore bodies on the surface or in old underground workings. Leach solution is applied either by piping or by percolation through overburden. Leach solution is then pumped from collection sumps to a metal recovery or precipitation facility. In situ leaching is most economical when the ore body is surrounded by an impervious layer, which minimizes loss of leach solutions. However, when water is sufficient as a leach solution, in situ leaching is economical even in pervious strata.

Leaching processes are used most often in gold (cyanide leach), uranium (water leach in situ), and copper operations (sulfuric acid).

The final waste type, mine water, is water that infiltrates a mine and must be removed to facilitate mining. The quantity and quality of the mine water handled varies from mine to mine; quantities may range from zero to thousands of liters per ton of ore mined. The number of mine water ponds at mine sites in the industry segments covered in this report is usually between one and six.[11]

2.4 WASTE QUANTITIES

Table 2-8 presents an estimate of the cumulative amount of tailings and mine waste generated by the mining and beneficiation of metallic ores, phosphate rock, and asbestos from 1910 through 1981. As shown, nearly 49 billion metric tons of waste have been generated by the mining and beneficiation of eight metals and two nonmetals. Copper, iron ore, and phosphate rock have produced over 85 percent of the total volume of waste.

Mining and beneficiating nonfuel ores and minerals generated approximately 2,000 million metric tons of waste in 1980.[12] The waste handled in the U.S. mining industry declined to 1,300 million metric tons for the industry as a whole in 1982.[13] The industry segments covered in this report are responsible for more than 90 percent of this nonfuel mining waste. The 1980 and 1982 estimated waste volumes for each segment are shown in Table 2-9. The copper mining segment alone generates approximately half of the waste produced by the metal mining segments, and one-third of the total waste. The phosphate mining industry is responsible for almost all waste from the nonmetal mining segments, and more than 25 percent of all mining waste discussed. Iron ore and uranium mining also generate large volumes of waste.

The waste for each mining segment is broken out by waste type for 1980 and 1982 in Tables 2-10 and 2-11, respectively. (Mine water quantities are variable and difficult to estimate accurately, and are not shown on these tables.) The waste tonnages shown in Tables 2-10 and 2-11 are estimates based on primary production data. Over half of all mining waste generated in these years was mine waste, and tailings accounted for slightly less than one-third of the total amount of waste.

The phosphate rock, uranium, copper, and iron ore mining segments were, in that order, the largest generators of mine waste in 1980, accounting for over

Table 2-8 Estimated Cumulative Mine Waste and Tailings Generated by the Mining and Beneficiation of Metallic Ores, Phosphate Rock and Asbestos, 1910 Through 1981 (millions of metric tons)

Mining industry segment	Tailings	Mine waste	Total waste
Metals:			
Copper	6,900	17,000	23,900
Gold	350	400	750
Iron ore	3,000	8,500	11,500
Lead	480	50	530
Molybdenum	500	370	870
Silver	50	30	80
Uranium	180	2,000	2,180
Zinc	730	70	800
Nonmetals:			
Phosphate rock	2,200	5,500	7,700
Asbestos	40	30	70
TOTAL	14,430	33,950	48,380

Source: Estimated by Charles River Associates 1985, based on Coppa 1984, BOM various years, and BOM 1980a.

Table 2-9 Estimated Volume of Waste Generated by the Mining and Beneficiation of Metallic Ores, Asbestos, Phosphate Rock, and Overburden From Uranium Mining[a] (millions of metric tons/year)

Mining industry segment	1980	1982
Metals:		
Copper	723	502
Gold[b]	38	74
Iron ore	350	177
Lead	11	11
Molybdenum	46	30
Silver	13	26
Uranium (mine waste only)	298	73
Zinc[c]	6	7
Other metals[d]	29	26
Subtotal	1,514	926
Nonmetals:		
Asbestos	7	6
Phosphate rock	500	403
Subtotal	507	409
TOTAL	2,021	1,335

[a] Excludes mine water.

[b] Excludes placer operations.

[c] About 4 million metric tons of saleable products are extracted before tailings disposal.

[d] Includes antimony, bauxite, beryllium, manganiferous ore, mercury, platinum, rare earth metals, tin, tungsten, and vanadium.

Source: Estimated by Charles River Associates 1985 based on BOM 1981a and 1983.

Table 2-10 Estimated Volume of Waste Generated by the Mining and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, and Overburden from Uranium Mining in 1980[a] (millions of metric tons)

Mining industry segment	Waste production			
	Mine waste	Tailings	Dump and heap leach wastes	Total
Metals:				
Copper	282	241	200 (Dump)	723
Gold[b]	25	10	3 (Heap)	38
Iron ore	200	150	--	350
Lead	1	10	--	11
Molybdenum	15	31	--	46
Silver	10	3	<1(Heap)	13
Uranium	298	NA	--	298
Zinc	1	5[c]	--	6
Other metals[d]	24	5	--	29
Subtotal	856	455	203	1,514
Nonmetals:				
Asbestos	5	2	--	7
Phosphate rock	348	152	--	500
Subtotal	353	154	--	507
TOTAL	1,209	609	203	2,021

NA indicates not applicable to this report.

[a] Excludes mine water.

[b] Excludes placer operations.

[c] About 4 million metric tons of saleable products are extracted before tailings disposal.

[d] Includes antimony, bauxite, beryllium, manganiferous ore, mercury, platinum, rare-earth metals, tin, tungsten, and vanadium.

Source: Estimated by Charles River Associates 1985 based on BOM 1981a.

Table 2-11 Estimated Volume of Waste Generated by the Mining and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, and Overburden from Uranium Mining in 1982[a]
(millions of metric tons)

Mining industry segment	Waste production			
	Mine waste	Tailings	Dump and heap leach wastes	Total
Metals:				
Copper	124	178	200 (Dump)	502
Gold[b]	39	24	11 (Heap)	74
Iron ore	102	75	--	177
Lead	2	9	--	11
Molybdenum	24	6	--	30
Silver	20	6	<1(Heap)	26
Uranium	73	NA	--	73
Zinc	1	6[c]	--	7
Other metals[d]	23	3	--	26
Subtotal	408	307	211	926
Nonmetals:				
Asbestos	4	2	--	6
Phosphate rock	294	109	--	403
Subtotal	298	111	--	409
TOTAL	706	418	211	1,335

NA indicates not applicable to this report.

[a] Excludes mine water.

[b] Excludes placer operations.

[c] About 4 million metric tons of saleable products are extracted before tailings disposal.

[d] Includes antimony, bauxite, beryllium, mercury, rare earth metals, tungsten, and vanadium.

Source: Estimated by Charles River Associates 1985 based on BOM 1983.

93 percent of the total in that category. These four segments were also the largest generators of mine waste in 1982, generating nearly 84 percent of the total.

More than 89 percent of tailings wastes were generated by copper, iron ore, and phosphate rock production in 1980; this percentage was almost 87 percent in 1982. Dump and heap leaching are confined to the copper, silver, and gold segments. The gold segment generated less than 2 percent of all leaching waste in 1980, but this increased to more than 5 percent in 1982. This twofold rise in the volume of gold leaching waste was caused by an increase in the use of the heap leaching method in this segment, a trend that is likely to continue because of the increased value of the gold and the decline in prices of many other metal commodities.

The wastes generated by the nonfuel mining industry are generally disposed of on site, and thus the geographic distribution of active mining waste management sites corresponds closely to the distribution of mine sites. Transportation or treatment of these wastes beyond that practiced in connection with wastewater treatment and disposal is not commonly practiced in most segments. Accordingly, the principal mining states, i.e., Arizona (copper), Minnesota (iron ore), New Mexico and Wyoming (uranium), and Florida (phosphate rock), are the states that produce the majority of all mining waste.[14]

2.5 SUMMARY

The major categories of waste are mine waste and mine water from mining operations, dump and heap leach wastes from leaching operations, and mill tailings from the beneficiation (concentration) of ores. In situ leaching of rock or in mines is performed in place. Annual waste generation totaled 2 billion metric tons in 1980 and 1.0 billion metric tons in 1982 for the metal mining segments and the phosphate and asbestos mining industries. Several mining segments are geographically restricted: lead (100 percent in Missouri); molybdenum (100 percent in Colorado); asbestos (75 percent in California); phosphate (74 percent in Florida); iron (70 percent in Minnesota); and copper (68 percent in Arizona). In both 1980 and 1982, the three segments generating the largest amounts of waste were copper, phosphate, and iron.

SECTION 2 FOOTNOTES

[1] BOM 1983.

[2] BOM 1983.

[3] U.S. Department of Commerce 1985.

[4] All mines are not censused every year. Other mines in the nonmetals industry segments include abrasives, asphalt, barite, boron minerals, diatomite, feldspar, fluorspar, graphite, greensand marl, gypsum, kyanite, lime, mica (scrap), perlite, potassium salts, pumice, salt, sodium carbonate, stone, sulfur, talc, vermiculite, and wollastonite. Clay and sand and gravel mines accounted for approximately 95 percent of all nonmetal mines in 1982.

[5] BOM 1981a.

[6] See also US EPA 1982a.

[7] Mountain States Research and Development, Inc. 1981.

[8] Mining and beneficiation methods are discussed in detail in EPA's final Development Document for Effluent Limitations Guidelines and Standards for the Ore Mining and Dressing Point Source Category.

[9] BOM 1981b.

[10] Martin and Mills 1976.

[11] PEDCo Environmental, Inc. 1984.

[12] Charles River Associates 1984a, based on BOM 1981a.

[13] BOM 1984.

[14] Charles River Associates 1985a.

SECTION 3

MANAGEMENT PRACTICES FOR MINING WASTES

3.1 OVERVIEW OF THE MINING WASTE MANAGEMENT PROCESS

Mine waste, tailings, heap and dump leach waste, and mine water can be managed in a variety of ways. Figure 3-1 provides an overview of the mining waste management process. As shown in the figure, mine waste may be used on or off site, disposed of in mine waste piles, or used in leach operations to recover additional valuable constituents from the ore. Similarly, tailings may be used on or off site, disposed of in tailings ponds,[1] or used in leach operations to recover valuable constituents in the tailings that are still present after milling processes have been completed. Tailings also may contain residues of the reagents used in flotation processes. These reagents include forms of cyanide (used in the leaching of gold and silver and in the separation of sulfide minerals), sulfuric acid used and formed in copper dump leaching, and various organic and inorganic compounds used in copper, lead and zinc flotation.[2]

Mine water may be discharged to surface streams (often after treatment) via National Pollutant Discharge Elimination System (NPDES) permitted outfalls, used as milling process makeup water (recycled), or used on site for other purposes (e.g., dust control, drilling fluids, sluicing solids back to the mine as backfill, etc.).

The recovery of valuable constituents from mine water (e.g., Ix treatment for uranium), from mill process solids, or from extraction from dump leach liquors could possibly be considered to be waste treatment processes, in that

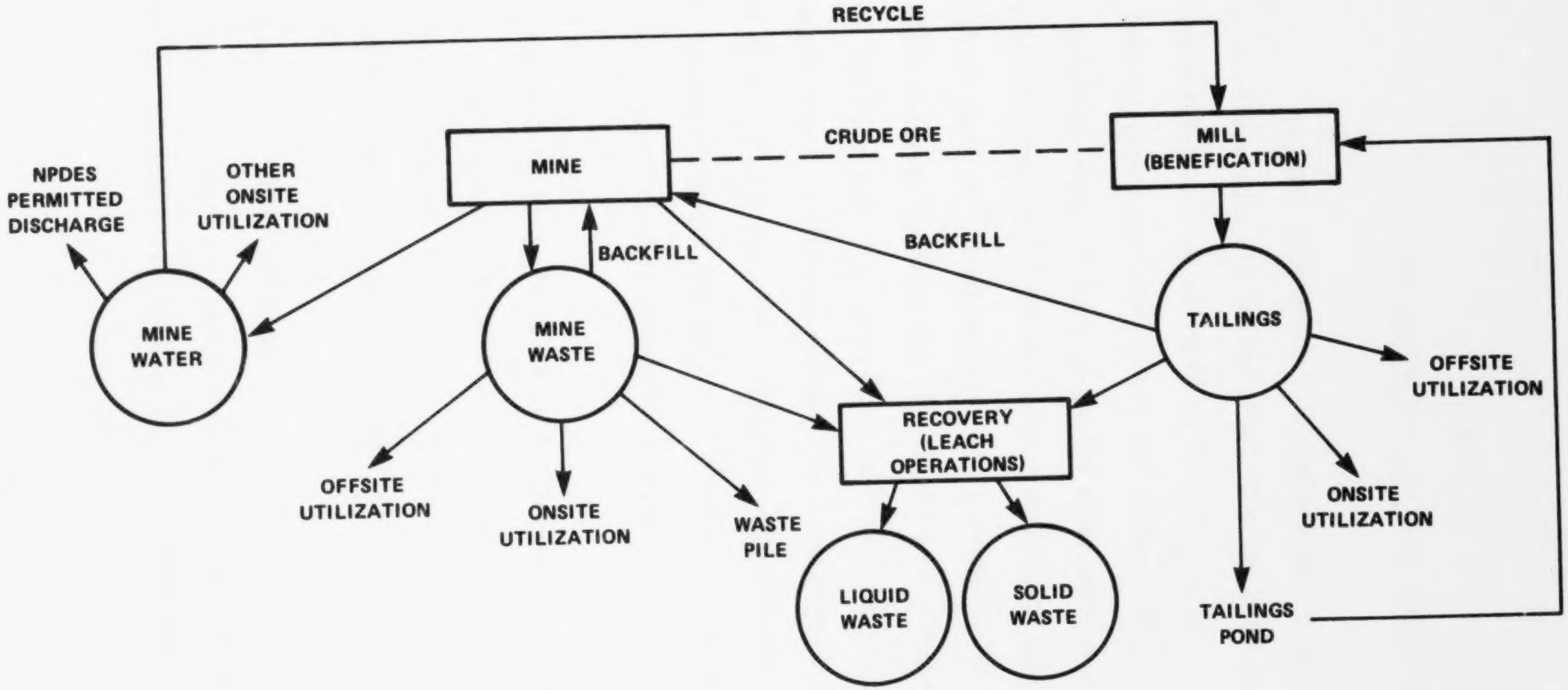


Figure 3-1 The mining waste management process

such recovery extracts metals or constituents that would otherwise be potentially hazardous or constituents of waste prior to disposal. However, the mining industry considers these processes to be extraction or beneficiation processes because they recover valuable products from materials that have metal concentrations below those in ore of a grade suitable or economical for milling and smelting.

Table 3-1 presents the volumes and percentages of mine waste and tailings that are currently managed according to the various practices shown in Figure 3-1 and mentioned above. The table shows that more than half of all mine waste and tailings is disposed of in piles and ponds, respectively.[3] Most onsite utilization of mine waste and tailings involves the dump leaching of copper mine waste and the use of sand tailings to build tailings impoundment dams in all industry segments.

The remainder of this section is divided into three parts. Section 3.2 describes waste management practices other than actual disposal. The section includes a discussion of recovery operations, process changes for waste volume reduction, waste treatment methods, onsite utilization of mine water, and offsite use of mine waste and mill tailings. It shows that although several alternatives to onsite land disposal of mining industry wastes are available, their effectiveness in reducing the amount of mining industry wastes is limited.

Section 3.3 describes some general considerations for locating waste disposal sites and specific aspects of waste disposal for tailings, mine waste, leached material, and mine water.

Section 3.4 examines the measures that can be used to limit or mitigate the hazards posed by mining industry wastes that are disposed of on site.

Table 3-1 Current Waste Management Practices

Waste type	Management practice	Volume (in millions of metric tons per year)	Percent of waste generated
Mine waste	Pile	569	56
	Onsite utilization	313[a]	31
	Backfill	86	9
	Offsite utilization	43	4
	Total	1,011	100
Tailings	Ponds	267	61
	Onsite utilization	141[b]	32
	Backfill	21	5
	Offsite utilization	8[c]	2
	Total	437	100

[a] Includes dump leach operations and starter dams for tailings impoundments.

[b] Includes the sand fraction used in building tailings impoundment dams.

[c] Includes 4 million metric tons of Tennessee zinc tailings sold as construction materials or soil supplements.

Source: Charles River Associates 1984a, based on U.S. Bureau of Mines data.

These measures are particularly important because most of the large volume of mining industry wastes will ultimately remain on or near the site. The mitigative measures considered are broadly categorized under inspection and detection measures, liquid control systems, and corrective action measures.

3.2 WASTE MANAGEMENT PRACTICES

Waste management practices include process modifications for waste or potential hazard minimization, recovery operations, treatment prior to land disposal, onsite use of mine water, and offsite use of mine waste and mill tailings. Each of these practices is discussed below.

3.2.1 Process Modifications for Waste Minimization

Although there are no practical means of reducing the volume of solid waste produced by mining and beneficiation operations, some changes in beneficiation processes can lead to changes in the chemical composition of the tailings released into tailings impoundments. For example, pilot studies have been conducted in which nontoxic reagents were substituted for cyanide compounds in the beneficiation of copper ores. Sodium sulfide and sodium bisulfide may be used as alternatives to sodium cyanide (see 47 FR 25693, June 14, 1982). Similarly, alkalinity in the beneficiation circuits can be maintained by reagents less toxic than ammonia. Lime is the reagent of choice in most instances, although some scaling has been reported.

Two copper mills have circuits separating pyritic material from sulfide ores to improve subsequent copper recovery. The pyrites are currently discharged to the tailings impoundments, but they could be segregated. If pyrites were not codisposed of with other gangue material, there would be a reduction in the potential for acid formation after closure of the tailings impoundment. However, the alkaline tailings and pond water may act to reduce this potential.

The thickened discharge method of tailings management involves partially dewatering the tailings slurry and discharging it from a single point. This results in a gently sloping, cone-shaped deposit. The water removed from the tailings can be treated and discharged or returned to the milling circuit. The dewatering costs associated with this method are offset by reduced earthwork costs. A disadvantage of the thickened discharge technique in some circumstances is that no water is stored with the tailings, which may mean that the dewatered slurry piles become sources of fugitive dust. The particle size distribution of the waste and the drying characteristics of the disposal area are important factors in determining the potential for fugitive dust emissions. Earthquake activity may also affect the stability of the dewatered slurry piles, depending on the location. The thickened discharge method is currently used to dispose of sand tailings in the Florida phosphate industry segment, and could be applied to other sectors.[4,5]

Biological acid leaching, a new process under development in Canada, may be a feasible substitute for current dump leaching practices. Unlike dump leaching operations, the new process does not convert the sulfur in the ore to sulfuric acid; instead, it converts it to elemental sulfur, which is both less hazardous to the environment and potentially saleable. The process is still in the pilot development stage; the economic and technical feasibility of large-scale operations of this type have not yet been demonstrated.[6]

3.2.2 Recovery Operations

Leaching is a process used to recover metal values from low-grade ore or tailings, and is a common practice in some mining segments (i.e., copper, gold, silver, and uranium). There are several types of leaching operations practiced, including in situ, dump, heap, and vat leaching. Acid solutions are commonly used for leaching in the copper segment of the mining industry.

Cyanide solutions are used to leach both gold and silver wastes as well as ores. The precious metals in cyanide leach solutions are removed in the process, and the partially spent cyanide solution is recycled back to the process for reuse. Leaching of phosphate rock and uranium wastes are also practiced.[7] In situ leaching in the uranium segment is practiced with water as the leach solution.

The purpose of using leaching techniques is to recover valuable metals from ores that would otherwise be uneconomical to mine. In situ and dump leaching techniques may cause environmental problems, in that an impermeable layer is not always placed or located between the low-grade ore and the surrounding soil, especially at older operations. However, it is in the miner's best interest to capture as much of the leachate in order to recover the metal values. The benefits of leaching are improved natural resource utilization and increased production of valuable metals such as gold, silver, and copper. The drawbacks of leaching, especially dump and in situ leaching, are that potentially corrosive (low-pH) or toxic (cyanide and/or toxic metals) products may seep into the ground below these operations. In ores that would naturally form acid drainage, leaching operations allow recovery of metals from ores that would naturally release these metals over a period of time.

In the copper, gold, and silver industries, technical efficiency and economic factors have made the recovery of mineral values by leaching processes economically feasible. Overburden, tailings, and other wastes will continue to be "remined" in the future, if extraction efficiencies continue to improve and if product prices exceed extraction costs.

Techniques other than leaching have been developed to recover valuable constituents from mine and mill wastes. Flotation can be used with copper mine waste, taconite (iron) tailings, and zinc mine waste.[8]

Pilot-scale research projects have also shown that it is technically feasible to use a high gradient magnetic separation process to produce an anorthosite concentrate, assaying at more than 28 percent alumina (Al_2O_3), from copper tailings. However, this has not proved economically competitive with alumina produced from bauxite by the Bayer process.[9]

3.2.3 Waste Treatment

Various oxidation systems have been developed to destroy cyanide compounds prior to discharge; however, most of the cyanide in cyanide leach processes is recycled back to the process for reuse. One system uses sodium hypochlorite and sodium hydroxide; another uses chlorine and sodium hydroxide.[10] Other processes have been used, including hydrogen peroxide oxidation, potassium permanganate, and chlorine dioxide. Destroying the cyanide used to leach metals may be feasible, using the new peroxide-thiosulfate process currently being developed by the Bureau of Mines (BOM).[11] In this method, hydrogen peroxide and sodium thiosulfate convert free and weakly complexed cyanide to thiocyanate. After the remaining complexed cyanide is precipitated and flocculated, the solution is filtered. Copper, iron, and other base metals associated with the gold and silver ore are removed along with the cyanide. However, thiocyanates have been shown to have latent toxic effects on fish; thiocyanate apparently accumulates in fish, only to be released in lethal form when the fish are stressed.[12]

Cyanide levels in froth flotation wastewater are generally low, and are the result of using cyanide to depress pyrites in the circuit. Ultraviolet radiation (from the sun) and simple aeration are often adequate to reduce the cyanide levels to detection levels.

Neutralization is a technically feasible method of treating corrosive acidic wastes. Chemical agents commonly used for this purpose include quicklime, limestone, hydrated or slaked lime, caustic soda, soda ash, and hydrated ammonia.[13]

The Effluent Limitations Guidelines and New Source Performance Standards for the ore mining and dressing point source category endorse the use of lime to maintain discharges within the 6.0 to 9.0 pH range. In fact, the permit issuer may allow the pH level in the final effluent to exceed 9.0 slightly, if that is required to meet discharge limitations for copper, lead, zinc, mercury, and cadmium.

Treatment of acidified mine waste or tailings is often a necessary prerequisite for revegetation. Hydrated lime or quicklime is used to increase the pH to 9.0 rapidly. For a slower but longer-lasting response, agricultural lime (limestone) is used. The lime is added in quantities great enough to neutralize the sulfuric acid that will be released by the future oxidation of pyritic material in the mine or mill waste.[14]

3.2.4 Onsite Use of Mine Water

Water generated by mine dewatering may be used in the milling process as makeup water (treatment may or may not be required), or used on site for dust control, sluicing solids to the mine as backfill or in cooling or drilling fluids. Depending on the water balance at a facility, managing the mine water may involve a combination of these uses. A large number of mining and beneficiation operations use mine water in the mill. In some cases, all of the water required by the mill operation is obtained from mine drainage, which eliminates the need for wells and a mine water treatment system, or greatly reduces the volume of mine water discharged. Using mine water containing relatively high concentrations of soluble metals for beneficiation makeup water is an effective treatment practice, because flotation circuits, which are typically alkaline, reduce the solubility of metals and thereby facilitate their recovery. In most cases, however, not all of the mine water is used in the beneficiating operations, because operators have little or no control over the quantity of water that infiltrates the mine. The unused portion of the mine water is generally stored in impoundments and discharged after treatment, in accordance with the provisions of an NPDES permit.[15]

3.2.5 Offsite Use of Mine Waste and Mill Tailings

Waste utilization practices include agricultural lime replacement, road and building construction, and the production of bricks, ceramics, and wallboard. These methods are discussed below and summarized in Table 3-2.

The most widespread use for these wastes is in the production of concrete and bituminous aggregates for road construction. Other applications in road construction include the use of these wastes in road bases, as embankments, and to make antiskid surfaces. Approximately 50 percent of the zinc tailings in Tennessee are sold for aggregate production.

Tennessee zinc tailings also may be used as a substitute for mortar or agricultural limestone; nearly 40 percent of these tailings are sold for these purposes. Tailings from mills processing zinc ores in New York and the Rocky Mountain states are not suitable as soil supplements, because these tailings have lower concentrations of calcium carbonate and higher concentrations of lead and cadmium. Similar concerns constrain the use of lead tailings in Missouri.[16]

Tailings from asbestos and molybdenum mining operations have been used in asphalt mixes for roads and parking lots. Phosphate, gold, and silver

Table 3-2 Uses of Mine Waste and Tailings

Use	Asbestos	Copper	Gold & silver	Iron ore/ taconite	Lead	Molybdenum	Phosphate	Uranium	Zinc
Material Use									
Soil Supplement									1
Wall Board Production	3								
Brick/Block Production	1	1	1	1					
Ceramic Products							1		
Anti-Skid Aggregate				3			1		
Embankments		3	3	3	3				
General Aggregate			3	3	3				
Fill or Pavement Base		3	3	3	3				
Asphalt Aggregate	2			3	3	3		1	3
Concrete Aggregate			3	3	3		1		3

Development Stage

1. Bench-scale research project
2. Full-scale demonstration project
3. Full-scale, sporadically practiced

Source: Based on Seitter and Hunt 1982.

tailings of sand and gravel size have been mixed with cement to form concrete for use in road construction. Lead, zinc, and iron ore tailings have been used for both concrete and bituminous aggregates. Mixtures of crushed waste rock, including waste material from copper, iron ore, lead, gold, and silver mines, have become embankments, fills, or pavement bases for many highways. Topsoil must be deposited over fills and embankments made with these materials to control erosion and permit the growth of vegetation. Taconite tailings have proved valuable as thin (less than 25 mm) road surface overlays, because they greatly enhance skid resistance.

The use of tailings to produce bricks, blocks, and ceramic products has not yet passed the bench-scale research stage. Copper mill tailings can be used in brick production if pyrites are first removed. Lightweight blocks made from taconite tailings have good structural characteristics but have not been marketed.

The most important constraints on the use of mining wastes are imposed by energy, economic, and logistic considerations. Material/metal recovery from mining wastes is economically attractive only when the price of the material recovered exceeds the costs of extraction. In recent years, mine product prices have been generally depressed, and extraction costs, especially energy-related costs, have risen. Similarly, using mining wastes to produce bricks or to construct roads is affected by such market constraints as transportation costs and competition with other sources located nearer to potential users.[17] Mining wastes, therefore, are competitive only when they can be marketed or used in the geographical area close to the originating mine.

Uses of mining wastes do not and will not keep pace with the approximately 1 to 2 billion metric tons of these wastes that may be generated each year. Long-term management of mining waste disposal sites will continue to be necessary for the foreseeable future. However, research on the cost-effective utilization of mining wastes is justified, because any new use that becomes widely practiced will help reduce the magnitude of the mining waste disposal problem.

3.3 WASTE SITING AND DISPOSAL METHODS

For technical and economic reasons, most mining waste is finally disposed of on the land. The primary considerations for locating a waste disposal area are discussed below. Specific waste disposal methods for mining wastes are also described.

3.3.1 Location and Siting

The topography, geography, and hydrogeology and, in some cases, meteorology, as well as population density of the geographical area in which a mine is located, affect the siting of the waste disposal area, the extent to which mitigative practices are required, and the types of mitigative systems that can be selected. The extent of the ore body, the quantity of waste to be generated, and the method of mining are also considered when siting a disposal area.

Owners and operators of mines built before 1970 generally located waste sites at the shortest and most easily traversed distance from the mine or mill, usually in a ravine or gully. Owners and operators of mines constructed since 1970 (when Federal and state environmental regulation greatly increased) have also considered the potential pollution problems associated with particular sites, such as siltation of surface waters, production of fugitive dust emissions, and contamination of ground water. Disposal locations chosen based on these considerations may have small upgradient drainage areas to reduce erosion potential, or may be underlain by impermeable strata to minimize percolation into ground water.

3.3.2 Waste Disposal Methods for Tailings

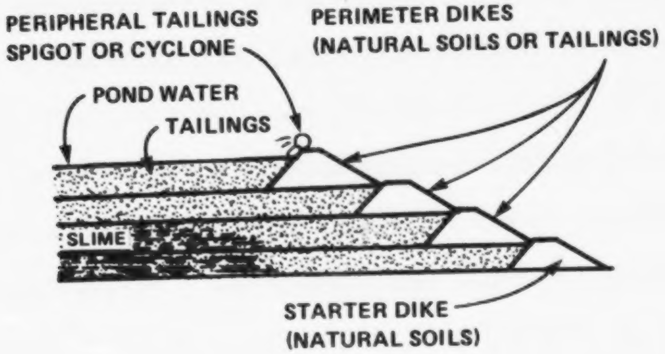
Waste disposal methods for tailings include: tailings ponds, stope[18] backfilling, below-grade disposal, and offshore disposal. As was shown in Table 3-1, more than half of the tailings are disposed of in tailings ponds. The size and design of the ponds vary widely by industry segment and location. Tailings disposal methods are discussed below.

(1) Tailings Impoundments. Tailings impoundments have been used at ore mills in the United States since the early 1900s. In recent years, they have become increasingly important and may account for as much as 20 percent of the construction cost of a mine/mill project.[19] Some ore bodies may not be exploited, because suitable sites for tailings disposal are not available within a practical distance.

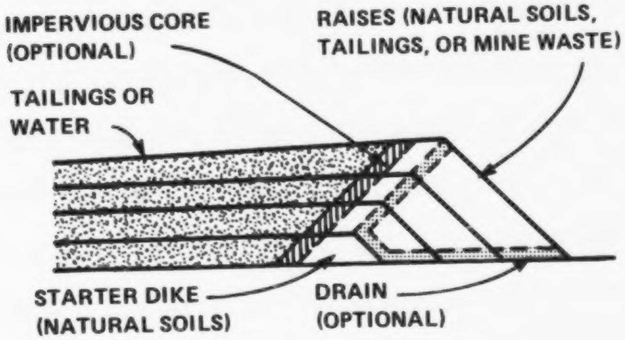
Tailings impoundments may serve several purposes. They retain water, making it available for recycling to the mill flotation circuits and other processes requiring water. They act as equilization basins, which assist in wastewater treatment process control and reagent addition control. They also protect the quality of surface waterways by preventing the release of suspended solids and dissolved chemicals. In fact, tailings impoundments in arid regions may per mill to achieve "zero discharge," eliminating the need for a point source discharge permit.

The design and construction of a tailings impoundment reflect the characteristics of the ore, the mine/mill, and the environment, especially the local topography. Three methods of dam building are commonly used: downstream, upstream, and centerline. Figure 3-2 depicts these methods.

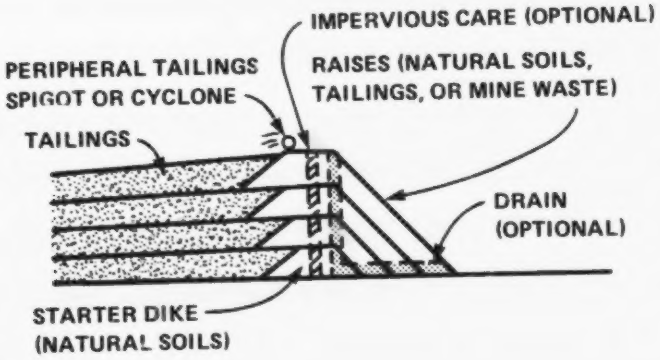
UPSTREAM METHOD


PERIPHERAL TAILINGS SPIGOT OR CYCLONE
PERIMETER DIKES (NATURAL SOILS OR TAILINGS)
POND WATER
TAILINGS
SLIME
STARTER DIKE (NATURAL SOILS)

DOWNSTREAM METHOD


IMPERVIOUS CORE (OPTIONAL)
RAISES (NATURAL SOILS, TAILINGS, OR MINE WASTE)
TAILINGS OR WATER
STARTER DIKE (NATURAL SOILS)
DRAIN (OPTIONAL)

CENTERLINE METHOD


IMPERVIOUS CARE (OPTIONAL)
PERIPHERAL TAILINGS SPIGOT OR CYCLONE
RAISES (NATURAL SOILS, TAILINGS, OR MINE WASTE)
TAILINGS
DRAIN (OPTIONAL)
STARTER DIKE (NATURAL SOILS)

Source: Vick 1981

Figure 3-2 Tailings dam construction methods

A common element in all three types is that they are usually raised sequentially as the level of tailings and/or effluent in the impoundment rises, in order to distribute construction costs more evenly over the life of the facility.[20]

With the downstream construction method, the embankment building material is added successively to the downstream side of the previously placed embankment, and the crest thus moves downstream. This system is costly but is compatible with any type of tailings and can be used for water storage. The upstream method is less costly but is not well suited to large inflows and water storage. The centerline method involves raising the dam in steps, with the centerline of the crest remaining above the starter dam.[21]

The starter dam or dike is typically built with natural soils, but mine waste can also be used. Subsequent increments are added from the coarse, sandy fraction of the tailings. This use of tailings constitutes the largest component of the 141 million metric tons of onsite utilization of tailings shown in Table 3-1. Installation of internal filters and drains lowers the water level within the sand dam and reduces the danger of overtopping, instability, or breaks induced by seismic (earthquake) activity.[22] Other protective measures include reduction of the catchment area by maintaining diversion ditches around the impoundment and careful control of water inflow and outflow to allow for seasonal and mill operation variations.[23] In summary, many tailings ponds and impoundments require some degree of seepage to maintain their structural integrity.

Upstream embankments are widely used by the copper industry in the southwest. Earthquake activity and high precipitation along the West Coast have fostered use of downstream and centerline dams. Downstream dams are also favored by the lead industry in Missouri and the phosphate industry in Florida.

(2) Stope Backfilling. This method, also referred to as sandfilling, involves converting a portion of the coarse fraction of tailings into a slurry and then injecting the slurry into the mined-out portions of stopes. Stope backfilling is currently practiced or is being considered as a method of disposing of such diverse materials as copper tailings, spent shale from oil shale retorts, and tailings from Wyoming trona (sodium carbonate) mines.[24]

The major disadvantages of stope backfilling are the introduction of additional water into the mine, which results in occasional spills of tailings, and the importation of supplemental waste material to make tailings embankments when too much coarse fraction has been removed from the tailings. The primary drawback to backfilling with fines (materials with small particle sizes) is the risk of poor drainage of the backfill material. In addition, although no supporting monitoring data are available, backfilling of tailings into underground mines may have an adverse impact on ground-water quality. For example, metals or other constituents may leach from the coarse tailings and reach the ground water when seepage from the backfilled stopes occurs.[25] This possibility increases when the coarse tailings contain pyrites, which generate sulfuric acid that decreases pH and increases the solubility of most toxic metals.

Stope backfilling as a tailings management alternative is not used on a national scale, because most of the industry segments covered in this report excavate their ores using surface mining techniques.

(3) Below-Grade Disposal. This method of tailings disposal consists of placing tailings in an excavated pit (in lieu of above-grade impoundments) so that at closure, the entire deposit is below the level of the original land surface. This method currently is unique to the uranium industry, which uses

it to reduce the likelihood of erosion. The embankments of conventional above-grade surface impoundments are subject to erosion and failure that could result in the release of tailings to the downgradient area. Below-grade disposal avoids both of these potential problems. This disposal method is costly unless mined-out pits can be used.[26,27] This method could be used for operations involving open-pit mining if a series of mined-out pits is available to receive mill tailings (or retorted shale).

(4) Offshore Disposal. In the past, offshore disposal has been a euphemism for dumping tailings into a large lake or the ocean without regard for environmental consequences. Recently, more responsible proposals have shown that if the tailings are chemically innocuous, are sufficiently coarse to settle rapidly with a minimum amount of turbidity, and are piped to deep-water areas to avoid the most biologically productive nearshore zones, offshore disposal may have reasonably small environmental impacts in certain specific cases. Even so, offshore disposal is not a widely accepted alternative within regulatory agencies in the United States and Canada, and few mines have been located near the ocean in the past. Technical arguments notwithstanding, recent experience indicates that most developed countries will not approve offshore disposal of tailings.[28]

3.3.3 Waste Disposal Methods for Mine Waste

As was shown in Table 3-1, an estimated 56 percent of the mine waste removed to gain access to an ore body is disposed of in mine waste piles near or adjacent to the mine. The overburden from open pit mines is usually discarded on the outside slopes of the pit. Approximately 9 percent of the mine waste is disposed of as part of the normal mining practice of immediately backfilling previously excavated areas; the trend in the mining industry is toward increasing this percentage. In surface mining, however, backfilling is only used when the overburden can be placed into adjacent areas that have been excavated. With some underground mining methods, waste rock is backfilled into previously mined sections as it is excavated, which eliminates the time and expense of hauling the material to the surface for stockpiling. These mining methods include cut-and-fill stoping and square-set stoping. These methods provide structural stability to the mined areas, in addition to serving as a means of waste disposal.[29]

3.3.4 Waste Disposal Methods for Dump Leach/Heap Leach Material

Whether or not active dump leach and heap leach operations are considered to be process operations rather than solid waste disposal practices, solid waste material remains after the completion of these operations. The current practice is to transport overburden and low-grade copper ore for dump leach processes (or waste and low-grade precious metal ore for heap leach operations) to leaching beds, where the dumped material is spread by bulldozers. Equipment travel on the leach dump compacts the top layer of the material; this layer is then scarified to facilitate infiltration of the leach solution. This process of layering and subsequent scarifying of the leach dump may continue for 50 years or more.[30] The leached waste material is not removed from the site of the operation, due to the immense size of these piles.

3.3.5 Waste Disposal Methods for Mine Water

Water produced from mine dewatering may be discharged directly or indirectly (after treatment such as settling) to a surface stream, used in the milling process as makeup water (treatment may or may not be required), pumped to a tailings pond, or used on site for dust control, cooling, or as drilling fluids, etc. (see Section 3.2.4). Depending on the water balance of the particular mine facility, mine water management may involve one or a combination of these methods.

Treatment of mine water in onsite impoundments is the management practice used when discharge or total recycling are not possible. Such treatments include simple settling, precipitation, the addition of coagulants and flocculants, or the removal of certain species (e.g., radium-226 removal by coprecipitation with barium chloride in mine water ponds in the uranium industry). Most mine water ponds are relatively small, shallow, excavated, unlined impoundments. The number of impoundments and their size depends on the volume of mine water handled and the treatment methods used. Larger impoundments or several impoundments in series are used to provide sufficient retention time for effective treatment. Discharge from mine water treatment ponds is usually to a surface stream via an NPDES-permitted outfall.[31]

3.4 MITIGATIVE MEASURES FOR LAND DISPOSAL SITES

Even if greater use is made of waste utilization and alternative waste disposal methods, the greatest portion of mining wastes will still be disposed of in land disposal facilities such as waste piles, tailings ponds, and settling impoundments. However, various measures are available to detect or mitigate the problems associated with the land disposal of mining wastes. These measures may be classified into four general types:

1. Detection and inspection measures determine whether problems are developing. These activities include ground-water monitoring and visual inspection of other systems, erosion control, dam stability, and runoff control.

2. Liquid control measures control the potential for liquid to come into contact with mining waste, and thus minimize surface water pollution and the amount of liquid available for leachate formation.
3. Containment systems prevent leachate from entering the ground water and posing a threat to human health and the environment. Two types of containment systems are considered here: containment systems designed to prevent leachate from entering the ground water (such as liners and systems designed to control plumes of contaminated ground water) and corrective action measures.
4. Security systems prevent entry to the waste management area by animals or by unauthorized persons. These systems protect the general public and prevent activities that might damage onsite control systems.

The waste management measures that are most relevant to individual waste management sites depend, in part, on the operational phase of the waste management site. Three operational phases are distinguished here:

1. Active site life is the period during which waste is being added to the disposal site. A disposal site may be closed even though the mine itself remains active.
2. Closure is the period immediately following active site life, in which various activities are undertaken to ensure adequate protection of human health and the environment during the post-closure phase, and to minimize maintenance activities in the post-closure phase.
3. Post-closure is the period following closure during which there are no further additions of waste to the site. The main post-closure activities are the monitoring of the site for leaks and the

maintenance of liquid control, containment, and security systems established during site life or at the time of closure.

Corrective action occurs after a plume of contaminated ground water or another environmental hazard is discovered. This may occur during active site life, at the time of closure, or during the post-closure phase.

The remainder of this section describes various mitigative measures appropriate to the management of mining waste during the active life of the site, the closure period, and the post-closure phase, and discusses appropriate corrective measures. Some of the measures described can be substituted for each other. In most cases, the ability of these measures, or combinations of measures, to limit threats to human health and the environment depends on specific site conditions; in addition, many of these measures have yet to be applied in the mining waste context. The discussion below describes the purposes and limitations of various management techniques, but data are not available to allow the efficacy of these techniques to be quantified. Table 3-3 shows the various measures discussed in this section, classified by operational phase of the site.

Where possible, EPA has estimated the percentage of mines in some industry segments where the following mitigative measures are currently used: ground-water monitoring, run-on/runoff controls for storm water, liners for tailings ponds, secondary leachate collection and removal, and closure procedures. EPA produced these estimates using the methodology described in Appendix B.

3.4.1 Mitigative Measures During Active Site Life

During the active life of a waste disposal facility, waste is continually being added to the waste material already at the site. The ongoing nature of the disposal process at active sites makes certain mitigative measures

Table 3-3 Mitigative Measures by Stage of Site Life

Stage of site life	Mitigative measure	Purpose
Active site life	Hydrogeologic evaluation and ground-water monitoring	Detection of contaminants
	Run-on/runoff control	Liquid control
	Liners	Containment
	Cutoff walls	Containment
	Leachate collection, removal, and treatment systems	Liquid control
	Security systems	Security of control systems and protection of public health
Closure	Continue measures initiated during active site life	All purposes mentioned above
	Wastewater treatment	Liquid control
	Pond sediment removal	Waste removal
	Dike stabilization	Liquid control
	Waste stabilization	Liquid control
	Installation of leachate collection, removal and treatment systems at surface impoundments	Liquid control
	Final cover	Liquid control
Post-closure	Ground-water monitoring	Detection of contaminants
	Inspect/maintain all existing systems	All purposes mentioned above
Corrective action	Interceptor wells	Containment
	Hydraulic barriers	Containment
	Grouting	Containment
	Cutoff walls	Containment
	Collection	Treatment

Source: Meridian Research, Inc. 1985.

inappropriate for use at such sites. For example, methods such as caps or covers that are designed to control the volume of liquids percolating into the site cannot be used. Similarly, liners and containment systems that underlie the waste area can most easily be put in place at new facilities. However, other mitigative measures, such as those discussed below, can be used at existing active waste disposal sites.

3.4.1.1 Ground-Water Monitoring and Hydrogeological Evaluation

The objectives of hydrogeological evaluation and ground-water monitoring at a waste disposal or tailings pond facility are (1) to identify potential pathways of leakage and contaminant transport by ground water; (2) to determine whether contamination of the ground water has occurred and, if so, the extent of contamination; and (3) if necessary, to generate the data needed to select and implement a mitigative strategy. At new facilities, the first step in this process is to evaluate the pollution potential of effluents from the site.[32] A thorough hydrogeological evaluation and ground-water monitoring program are then conducted to characterize background or natural conditions at the site. In some cases, it may be necessary, prior to siting the monitoring wells, to simulate baseline and potential ground-water pathways by means of hydraulic or solute transport models.[33] Particularly in areas close to dams or dikes, hydrogeological evaluations are necessary to determine probable seepage paths and to establish flow rates to be used in the design of dikes, cutoff walls, and liners. Ground-water monitoring is also an important means of evaluating the initial and long-term effectiveness of the engineering and site preparation measures used at a particular site.

Depending on the specific characteristics and requirements of a given site, monitoring programs range in complexity from a simple determination of the presence or absence of a particular waste constituent in a few wells to an extensive analysis of many constituents in many wells, using well clusters open at different depths, aquifer tests, and geophysical measurements.[34,35] The complexity of an effective ground-water monitoring program is directly related to the size of the waste management project, the nature of the waste materials, and the characteristics of the local hydrogeology.

Using ground-water monitoring to assess conditions at a site has some limitations. Because a monitoring well characterizes only one point in an aquifer, results obtained at the well may not be representative of site conditions, especially in geologically complex areas. Another limitation of ground-water monitoring is that some knowledge of site conditions, such as ground-water flow rate and direction, is necessary before the monitoring wells can be placed properly. In addition, because ground-water flow is extremely slow, long-term monitoring over several months or years may be required to characterize the situation accurately. In some circumstances, the flow patterns of ground water through fractures may be sufficiently complex to frustrate even the most intensive monitoring effort.[36,37]

Waste disposal facilities in the mining industry are so large that horizontal and vertical distances between hydraulically upgradient, and therefore unimpacted, areas and areas that are downgradient, and therefore likely to be impacted, can be very great. The variation in natural conditions over such large distances (thousands of meters) can greatly complicate hydrogeological studies. In some cases, the presence of several active, inactive, or abandoned waste disposal sites or mines in the area also complicates ground-water quality and flow patterns, making ground-water monitoring and hydrogeologic evaluation more difficult.[38,39]

Nevertheless, hydrogeologic evaluation and ground-water monitoring remain the only methods for determining whether there is a danger of offsite movement of contamination from mining wastes. Because of the size and complexity of many mining waste sites, the need for detailed hydrogeologic evaluation and careful interpretation of ground-water monitoring results may be greater than for other types of hazardous waste management facilities.

Tables 3-4 and 3-5 show the extent to which ground-water monitoring, practiced voluntarily or in compliance with State regulations and adequate to satisfy current RCRA requirements, is performed at heap/dump leach operations and tailings ponds in the various mining industry segments. (Ground-water monitoring is not normally performed at mine waste disposal sites.) Ground-water monitoring of gold and silver heap leach operations adequate to satisfy current RCRA requirements is currently practiced at all of the gold and silver mine sites studied by EPA where there are heap leach operations. Ground-water monitoring adequate to satisfy RCRA requirements is currently practiced at two of the nine copper dump leach operations studied by EPA.

Monitoring of ground water is also practiced at all of the gold and silver tailings ponds and at 2 of the 12 copper tailings ponds studied by EPA. It is not performed at any of the lead or zinc tailings ponds studied by EPA.

3.4.1.2 Run-on/Runoff Controls

Run-on/runoff controls can be divided into three categories: diversion methods, containment systems, and runoff acceleration practices. Diversion systems prevent offsite water from entering the site and causing erosion and flooding. Containment involves the collection of onsite stormwater or dike seepage in holding or evaporation ponds for the treatment necessary for final disposal or to prepare the waste for recycling.

Table 3-4 Extent of Ground-Water Monitoring of Heap/Dump Leach Waste, by Industry Segment

Mining industry segment	Number of mine sites in data base that generate heap/dump leach waste	Number of mine sites that monitor ground water at heap/dump leach waste operations[a]	States requiring ground-water monitoring or having mine sites that monitor ground water at heap/dump leach waste operations[b,c]
Copper	9	2 (22%)	Arizona, New Mexico
Gold	5	5 (100%)	Montana, Nevada, Colorado, New Mexico, South Dakota
Silver	1	1 (100%)	Nevada

[a] Sites are identified as having ground-water monitoring only when such monitoring is adequate to satisfy current RCRA requirements.

[b] This column includes only those states where ground-water monitoring requirements are at least as stringent as required by RCRA.

[c] This column includes only the states generating large amounts of mining industry waste in the affected industry sectors.

Source: Charles River Associates 1984 and 1985c.

Table 3-5 Extent of Ground-Water Monitoring of Tailings Ponds, by Industry Segment

Mining industry segment	Number of mine sites in data that generate tailings	Number of mine sites that monitor ground water at tailings ponds[a]	States requiring ground-water monitoring or having mine sites that monitor ground water at tailings ponds[b,c]
Copper	12	2 (17%)	New Mexico, Colorado, California, Arizona
Gold	7	7 (100%)	Arizona, South Dakota, Nevada
Lead	6	0	
Phosphate	8	1 (13%)	Florida, North Carolina
Silver	8	8 (100%)	Montana, Idaho, Colorado, Utah
Zinc	6	0	

[a] Sites are identified as having ground-water monitoring only when such monitoring is adequate to satisfy current RCRA requirements.

[b] This column includes only those states where ground-water monitoring requirements are at least as stringent as required by RCRA.

[c] This column includes only the states generating large amounts of mining industry waste in the affected industry segments.

Source: Charles River Associates 1984 and 1985c.

Surface water diversion ditches consist of canals, channels, or pipes that totally or partially surround waste piles, tailings embankments, pits, or ponds to divert the surface water around them and back into the natural stream channel downgradient to the waste area. The most important functions of ditch systems are to minimize downstream environmental damage, relieve dike stresses to reduce the chance of failure, diminish erosion of the waste embankment, and reduce the volume of water requiring environmental monitoring.[40,41] Perimeter ditches also help to recover supernatant for recycling, collect and drain dike seepage, and collect onsite storm runoff for transport to a containment treatment system. When wastewater requires treatment before release, a suitable ditch network is constructed to prevent uncontaminated offsite or onsite runoff from mixing with onsite wastewater streams.

Table 3-6 shows the extent for which mine waste piles studied by EPA have run-on/runoff controls for storm water adequate to satisfy current RCRA requirements. Run-on controls for mine waste that are adequate to satisfy RCRA exist only at three mines studied by EPA in the gold industry sector. Runoff controls exist at these same three mines and at one silver mine in Colorado.

3.4.1.3 Liners

Lining the entire waste area and the upstream slope of the embankment may prevent seepage. Liners can be formed from natural earthen (clay) materials, synthetic materials, or a combination of these. Commercial bentonite can be added to fine-textured soils to reduce their permeability to very low levels. Synthetic liner materials include soil cements, treated bentonite, petroleum derivatives, plastics, elastomers, and rubber. These liners are generally more expensive than liners made of earthen materials, and careful earthwork is

best copy available

Table 3-6 Extent of Run-on/Runoff Controls for Stormwater for Mine Waste, by Industry Segment

Mining industry segment	No. mines in data base that generate mine waste	No. mine sites with run-on controls[a]	No. mine sites with runoff controls[b]	States requiring run-on/runoff controls or having mine sites with	
				Run-on[c] controls	Runoff[c] controls
Copper	13	0	0		
Gold	11	3 (27%)	3 (27%)	Montana, California	Montana, California
Lead	7	0	0		
Phosphate	18	0	1		N. Carolina
Silver	9	0	1 (11%)		Colorado
Uranium	9	0	0		
Zinc	7	0	0		

[a] Sites are identified as having run-on controls only when these controls are adequate to satisfy current RCRA requirements.

[b] Sites are identifed as having runoff controls only when these controls are adequate to satisfy current RCRA requirements.

[c] These columns include only the states generating large amounts of mining industry waste in the affected industry segments.

Source: Charles River Associates 1984 and 1985c.

required to prepare the ground surface even when these synthetic materials are used. If appropriate earthen liner materials are not readily available, synthetic liners may be more economical. Liner materials must be resistant to the potential corrosive effects of the waste and to damage from sunlight (if the liner is not covered immediately after placement).[42]

Although both synthetic and natural liners can be used cost-effectively in relatively small disposal areas, they have not been used in the very large waste facilities that are typical of mining industry waste sites (some of which cover a square kilometer or more); and they may in fact not be feasible at such sites.[43] Experience is inadequate to evaluate the performance of liners at large-area, large-volume sites. Lining large areas with synthetic (membrane-type) liners would require many liners to be fastened together to form a single large liner; each seam represents a point of potential failure. If a liner underlying such a large waste area failed, it would be impossible to repair.[44]

Installing liners at existing disposal areas in this industry would require moving billions of tons (approximately 50 billion tons) of material that has been deposited over the years. Many active disposal sites have been used for many years, and the areas are continually built up. Movement of these materials to new lined sites severely affects the cost of operations at these sites.

Table 3-7 shows the extent of the current use of tailings pond liners adequate to satisfy current RCRA requirements, for mines studied by EPA. Mine waste piles are not normally lined. According to Table 3-7, the majority of tailings ponds at mine sites studied by EPA in the silver and zinc industry segments are currently lined. Tailings ponds at mines studied by EPA in the

Table 3-7 Extent of Tailings Pond Liner Use, by Industry Segment

Mining industry segment	Number of mines in data base that use tailings pond liners	Number of mine sites having lined tailings ponds[a]	States requiring liners or having mine sites with lined tailings ponds[b,c]
Copper	12	0	
Gold	6	1 (17%)	Nevada
Lead	6	0	
Phosphate	18	0	
Silver	8	6 (75%)	Idaho, Utah
Zinc	6	4 (67%)	Tennessee

[a] Sites are identified as having lined tailings ponds only when the liner is adequate to satisfy current RCRA requirements.

[b] This column includes only those states where liner requirements are at least as stringent as those required by RCRA.

[c] This column includes only the states generating large amounts of mining industry waste in the affected industry segments.

Source: Charles River Associates 1984 and 1985c.

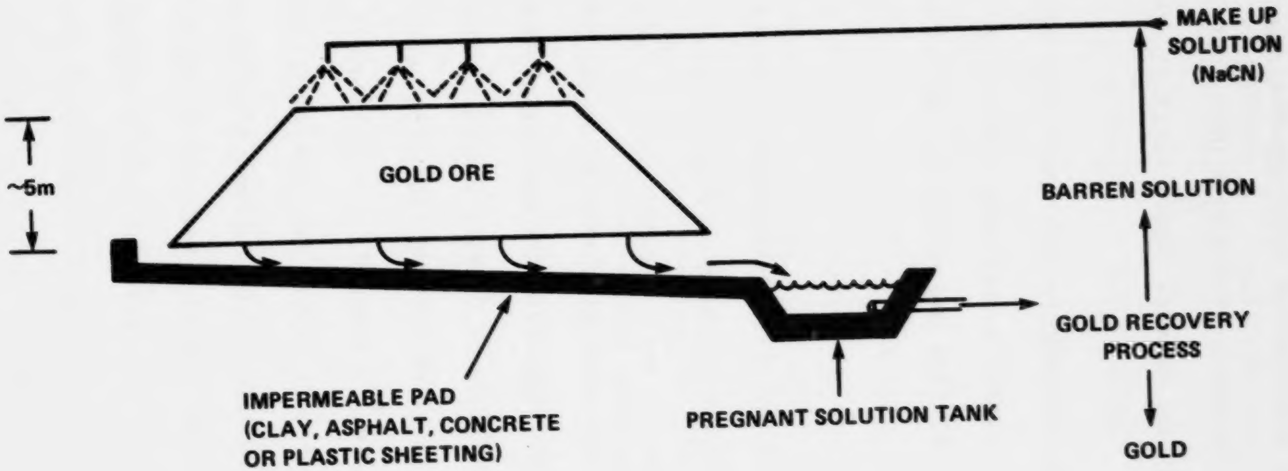
copper, lead, and phosphate industry segments are not lined. One of the six tailings ponds at mines studied by EPA in the gold industry segment is currently lined.

Regulations promulgated in 40 CFR Part 192 required that new uranium mill tailings impoundments be lined. Synthetic liners have been installed at three uranium mill tailings impoundments and natural liners exist at other uranium tailings impoundments.

Many mines studied by EPA have impermeable pads under heap leach piles. Figure 3-3 shows an impermeable pad under a gold heap leach pile. These pads aid in the collection of valuable leachate and reduce the pollution potential at these sites.

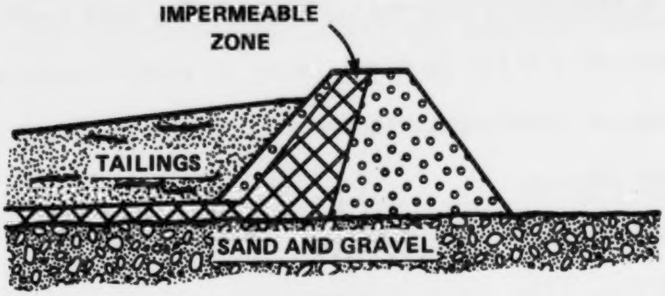
3.4.1.4 Cutoff Walls

Seepage outflow can be minimized by placing impermeable blankets or zones in the embankment or foundations, as illustrated in Figure 3-4A. A cutoff wall of the type shown in Figure 3-4B can be used in cases where a relatively impervious layer underlies a pervious layer at a shallow depth. The impervious core below the embankment will cut off the flow through the shallow, pervious portion of the foundation. A cutoff wall is usually placed toward the upstream portion of the embankment section to allow drained conditions under as much of the embankment section as practicable.[45] However, if total cutoff of seepage is desired (illustrated in Figure 3-4C), the cutoff wall can be installed far downstream, and the seepage can be removed from the drainage trench, pumped back to the impoundment, and then returned to the mill, or it can be pumped to a treatment plant and then released into a natural channel. A small amount of seepage will percolate downward, even through nearly impervious natural materials, from any unlined portion of the waste disposal

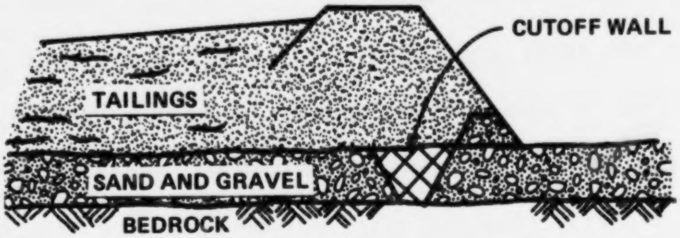


Source: PEDCo Environmental, Inc. 1985

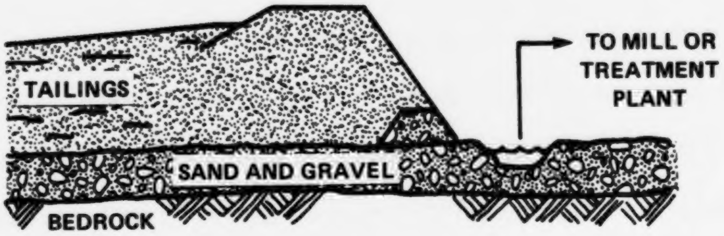
Figure 3-3 Impermeable pad under a gold heap leach pile



A. BLANKET AND CORE METHOD



B. FOUNDATION CUTOFF WALL METHOD



C. CUTOFF WALL AND OPEN TRENCH METHOD

Source: PEDCo Environmental, Inc. 1984

Figure 3-4 Some methods used to minimize seepage outflow

area; additional monitoring wells may be required in such cases. When the foundation consists of a thick pervious layer or several pervious layers separated by strata or impervious materials, a drainage trench can be used to remove some of the seepage.

3.4.1.5 Leachate Collection, Removal, and Treatment

During active site life, it is necessary to collect, remove, and treat leachate from lined waste piles to prevent the leachate from building up above the liner. Leachate collection prevents high moisture content at the base of the pile from deforming the structure of the pile. For small lined areas of facilities, an adequate leachate collection system may consist of a sump with a pump to collect the waste and pipe it to a lined impoundment for treatment. In larger facilities, a zone of sand, gravel, or coarse rock may be placed below the waste and drained. Such a system may be augmented by perforated pipe to increase capacity, and may also include collector trenches in cases in which the system emerges onto a broad, level area. Collector trenches may be useful even when no liners are used. Collected leachate must be treated and disposed of by such treatment methods as neutralization and precipitation, as discussed above.

At heap or dump leach operations, secondary leachate collection systems, consisting of leachate collection sumps and ditches, serve to interrupt liquids escaping the primary recirculating leaching system. The extent of adequate secondary leachate collection and removal from heap/dump leach waste and from tailings ponds is shown in Tables 3-8 and 3-9, respectively. Of the gold mines studied by EPA, only one had a secondary leachate collection and removal system in place that was adequate to satisfy current RCRA requirements for such systems. Secondary collection and removal of leachate from tailings

Table 3-8 Extent of Secondary Leachate Collection and Removal from Heap/Dump Leach Waste, by Industry Segment

Mining industry segment	Number of mines in data base that generate heap/dump leach waste	Number of mine sites that collect and remove leachate from heap/dump leach waste[a]	States requiring secondary leachate collection and removal or having mine sites that collect and remove leachate from heap/dump leach waste[b,c]
Copper	9	0	
Gold	5	1 (20%)	New Mexico, Nevada
Silver	2	0	

[a] Sites are identified as having secondary leachate collection and removal systems only when the system is adequate to satisfy current RCRA requirements.

[b] This column includes only those states where leachate collection and removal requirements are at least as stringent as those required by RCRA.

[c] This column includes only the states generating large amounts of mining industry waste in the affected industry segments.

Source: Charles River Associates 1984 and 1985c.

Table 3-9 Extent of Secondary Leachate Collection and Removal from Tailings Ponds, by Industry Segment

Mining industry segment	Number of mines in data base that generate tailings	Number of mine sites that collect and remove leachate from tailings ponds[a]	States requiring secondary leachate collection and removal or having mine sites that collect and remove leachate from tailings ponds[b,c]
Copper	12	0	
Gold	7	2 (29%)	California, South Dakota, Nevada
Lead	6	0	
Phosphate	18	0	
Silver	8	2 (25%)	Montana, Colorado, Idaho, Utah
Zinc	6	0	

[a] Sites are identified as having secondary leachate collection and removal systems only when the system is adequate to satisfy current RCRA requirements.

[b] This column includes only those states where leachate collection and removal requirements are at least as stringent as those required by RCRA.

[c] This column includes only the states generating large amounts of mining industry waste in the affected industry segments.

Source: Charles River Associates 1984 and 1985c.

ponds are practiced only at two gold mine sites studied by EPA, as shown in Table 3-9.

3.4.1.6 Security Measures

During the active site life phase of operations, the mining industry implements security measures that range from posting "No Trespassing" signs to installing comprehensive systems of locked gates and fencing and using security guards. Fencing material ranges from chain link to barbed wire. The extent of the security measures employed depends on the severity of the hazards existing at the mine site, the value of the material being mined or milled, and the proximity of the mine site to populated areas. Posting security guards has an additional benefit, because these employees can also be assigned facility inspection duties, such as checking runoff dikes. At active and inactive asbestos waste disposal sites, existing EPA regulations (40 CFR Part 61) require security measures.

3.4.2 Mitigative Measures at Closure

The mitigative methods described above for the active site life phase remain applicable during the closure phase. In addition, other activities may be necessary or desirable. For example, tailings impoundments may be dewatered and stabilized; these are essential steps if a cap and cover are to be added. A cap and cover can be placed over the site to minimize contact of the waste with the environment and to protect the waste from rainfall, which increases the volume of leachate formed.

3.4.2.1 Wastewater Treatment

The wastewater that remains onsite after active mining and milling operations have ceased may be treated and then discharged or be transported to a licensed disposal site.

3.4.2.2 Wastewater Pond Sediment Removal

The sediment that is collected in wastewater treatment and retention ponds often contains settled solids created during the mining or milling processes, precipitated metals, and process chemicals such as flotation reagents. Assessment of the potential hazards must be made during the active life of the mine and at closure, in order to properly dispose of and manage these wastes. The quality of these sediments varies widely, and some sediments may require removal at closure to reduce potential hazards, while other sediments may pose little or no risk to humans or the environment.

3.4.2.3 Dike Stabilization

A major consideration in the closure of a waste disposal site or area is the structural integrity of the dike(s) constructed to confine the waste.[46,47] Various methods of slope stabilization, such as slope modification and/or placement of waste rock (rip-rap), topsoil, vegetation, and chemical stabilizers, may be used during the active or final closure phases of the life of the impoundment to minimize erosion and siltation.[48] Closure of a diked impoundment may require an assessment of the ability of the dike system to withstand additional loads, which may include the weight of several layers of a capping system (clay, drainage layer, and topsoil cover) and of the construction equipment used to place and compact the final cover.[49] The long-term control of water behind the dike is a major factor in the stability of dikes and prevention of catastrophic failure.

3.4.2.4 Waste Stabilization

Since wastes remain in place after closure of the waste piles and ponds, proper consolidation and stabilization of the wastes are necessary to ensure long-term support for the final cover when it is emplaced. The initial step in stabilizing tailings is dewatering the wastes. At some sites (e.g., copper tailings ponds located in the arid Southwest), passive dewatering using natural evaporation and drainage mechanisms may be sufficient to remove free-standing water and to dewater the tailings. At other sites, active dewatering using pumps to remove liquids within the impoundment or from ponds on the impoundment surface may also be required in conjunction with passive dewatering mechanisms. The liquids collected during dewatering operations may require treatment before they are discharged or disposed of.

The wastes within the impoundment must also be capable of bearing the loadings imposed by the final cover system and the construction equipment used to apply this system. Tests can be used to estimate the anticipated amount of waste settlement and any differential settling across the waste site likely to be caused by increased loads.[50] The results of these tests may indicate the need for further dewatering, for redistribution of the wastes or compaction of the material (e.g., mechanical compaction such as with a sheepfoot roller), or for implementing methods of minimizing differential settlement.

3.4.2.5 Installation of Leachate Collection, Treatment, and Removal Systems for Lined Surface Impoundments

In order for these systems to be effective in collecting leachate, the post-closure needs of the system must be integrated into the initial design of the impoundment.

3.4.2.6 Final Cover System

The proper installation of a final cover system over the exposed surfaces of the waste impoundment, mine waste pile, leach dumps, etc., helps ensure control of erosion, fugitive dust, and surface water infiltration; promotes proper drainage; and creates an area that is aesthetically pleasing and amenable to alternative land uses. This cover system typically consists of the following components:

- A low-permeability clay layer or synthetic membrane overlying the waste material;
- A middle drainage layer of moderate to high permeability; and
- A top cover of topsoil and vegetation, except in the arid regions of the Western United States, where a rock cover is more effective for preventing erosion and breaching.[51,52]

The function of the low permeability material overlying the waste is to prevent the infiltration of precipitation, minimize leachate generation, and prevent the migration of potentially hazardous waste constituents from the waste into the ground water.[53] To prevent excessive leachate buildup, the low permeability layer should be at least as impermeable as the liner, if present.

If the final cover system is to be vegetated, a drainage layer of sand or gravel having low hydraulic conductivity is laid over the impermeable cap. This layer is graded (at least 2 percent) to allow the precipitation infiltrating the vegetative cover to drain rapidly, thus minimizing the hydraulic head on the clay cap or synthetic liner. Then, depending on the gradation, this layer is overlaid by a filter to prevent clogging.

Except in arid regions, the top layer of the cover system consists of topsoil capable of sustaining vegetation. Two feet of soil are considered adequate to accommodate the root systems of most nonwoody vegetative covers and to provide a degree of protection from root damage to the underlying clay or synthetic liner.[54] Wide variance in climatological factors and soil conditions, and therefore in subsequent growing conditions, affects the level of effort required to revegetate mined land successfully. For example, much less work is required at a Florida phosphate mine, where conditions are favorable (fertile soils, adequate water, and long growing seasons) than at a southwestern copper facility, where a combination of poor soils (e.g., high in salts and sulfides, low in nutrients) and an arid climate may require managers to introduce nonnative plant species, install irrigation systems, and provide constant maintenance to develop and sustain the vegetative cover. Revegetation also requires extra effort at sites in mountainous terrain where erosion rates are often high, growing seasons are short, and winters are long and severe.

Tables 3-10 through 3-12 show the number of mine sites studied by EPA where some types of closure activity are performed. Mines in many of the industry segments stabilize their wastes, install some kind of cap, and revegetate during the closure phase. For example, mine waste piles generated by the gold industry in California are contoured for stability and revegetated. For tailings generated by the phosphate industry in North Carolina, reclamation consists of covering the tailings with sand to increase stability, adding topsoil, and revegetating. Similarly, closure of tailings piles at sites in the gold and silver industries in Montana consists of compacting, grading, capping the tailings with rock and topsoil, and revegetating. Although waste stabilization, capping, reclamation, and revegetation appear to be common waste management practices in many industry segments, installing a final cover, consisting of a low-permeability clay layer or a synthetic membrane overlying the waste material, is not a mitigative practice used in the mining industry.[55] However, asbestos waste piles must be covered daily, as required by EPA regulations in 40 CFR Part 61, if there are visible emissions to the outside air.

Table 3-10 Closure Activities for Mine Waste, by Industry Segment

Mining industry segment	Number of mines in data base that generate mine waste	Number of mines performing some types of closure activity	States requiring some types of closure activity or having mine sites that perform some types of closure activity[a]
Gold	6	2 (33%)	California, Colorado
Phosphate	11	11 (100%)	Florida, Idaho
Silver	5	4 (80%)	Idaho, Colorado, Utah
Uranium	6	6 (100%)	Colorado, Wyoming

[a] This column includes only the states generating large amounts of mining industry waste in the affected industry segments.

Source: Charles Rivers Associates 1984 and 1985c.

Table 3-11 Extent of Closure Activities for Heap/Dump Leach Waste, by Industry Segment

Mining industry segment	Number of mines in data base that generate heap/dump leach waste	Number of mines performing some types of closure activity	States requiring some types of closure activity or having mine sites that perform some types of closure activity[a]
Copper	8	1 (13%)	Utah
Gold	5	0	
Silver	1	0	

[a] This column includes only the states generating large amounts of mining industry waste in the affected industry segments.

Source: Charles River Associates 1984 and 1985c.

Table 3-12 Closure Activities for Tailings Impoundments, by Industry Segment

Mining industry segment	Number of mines in data base that generate tailings	Number of mines performing some types of closure activity	States requiring some types of closure activity or having mine sites that perform some types of closure activity[a]
Copper	4	1 (25%)	Utah, New Mexico
Gold	7	3 (43%)	South Dakota, California, Arizona, Montana, Nevada
Lead	4	0	
Phosphate	12	12 (100%)	Florida, Idaho, North Carolina
Silver	4	4 (100%)	Idaho, Colorado, Utah Nevada, Montana
Zinc	3	1 (33%)	

[a] This column includes only the states generating large amounts of mining industry waste in the affected industry sectors.

Source: Charles River Associates 1984 and 1985c.

3.4.3 Mitigative Measures During Post-Closure

At certain sites during the post-closure phase, it is necessary to continue to support the waste management methods applied during the active and closure phases of site life. Many post-closure activities, such as inspection, are routine during active site life but require special effort to maintain once the site has been closed. For example, inspection activities after site closure should be part of a program of regularly scheduled visits.

Inspection and detection activities during the post-closure period may consist of the following:

- Assessment of the density, cover, and composition of vegetation species to evaluate revegetation success;
- Visual or photographic inspection to detect rill and gully erosion;
- Analysis of data on ground-water quality to define contaminant migration and dilution and to determine the effectiveness of liners, cutoff walls, or other containment systems;
- Evaluation of data on ground-water level to define ground-water recovery rates and levels;
- Visual or photographic inspection of stream and drainage channels to determine migration rates and patterns;
- Monitoring of subsidence; and
- Visual and photographic inspection after severe meteorological events (severe precipitation or drought) or other natural phenomena (e.g., earthquakes).[56,57]

Maintenance conducted during the post-closure period may consist of the following:

- Reseeding areas that have not been successfully revegetated;
- Repairing or replacing security fences, gates, locks, and warning signs;
- Maintaining collection and treatment systems;
- Maintaining monitoring wells and replacing them as necessary;

- Replacing rip-rap to control the migration of stream and drainage channels and the effects of flooding;
- Replacing top soil and rock covers to control rill and gully erosion; and
- Eliminating trees and other deep-rooted vegetation that may damage covers and liners.[58,59]

3.4.4 Corrective Action Measures

The corrective action measures described below may be necessary if a plume of contaminated ground water above some threshold limits has been detected. In this phase, the two major activities are additional hydrogeologic evaluation and controlling the plume. These processes are described below. Corrective action measures have not normally been performed at mining facilities in the past.

3.4.4.1 Hydrogeological Evaluation

Once ground-water contamination has been detected by the ground-water monitoring system, an extensive hydrogeological evaluation is usually needed to determine the size, depth, and rate of flow of the contaminated plume. The methods and limitations of hydrogeological evaluations in the corrective action stage are similar to those that apply to these evaluations during active site life.

3.4.4.2 Interceptor Wells

Seepage losses through the deep pervious foundation of a waste disposal facility can be reduced by installing interceptor wells at points that intersect the plumes of contaminated seepage in the saturated zone.[60] Comprehensive hydrogeological explorations and evaluations are required to site these wells properly. The intercepted seepage may be pumped directly to a mill or pond if water balances permit, or it may be treated before being returned to the mill or discharged.

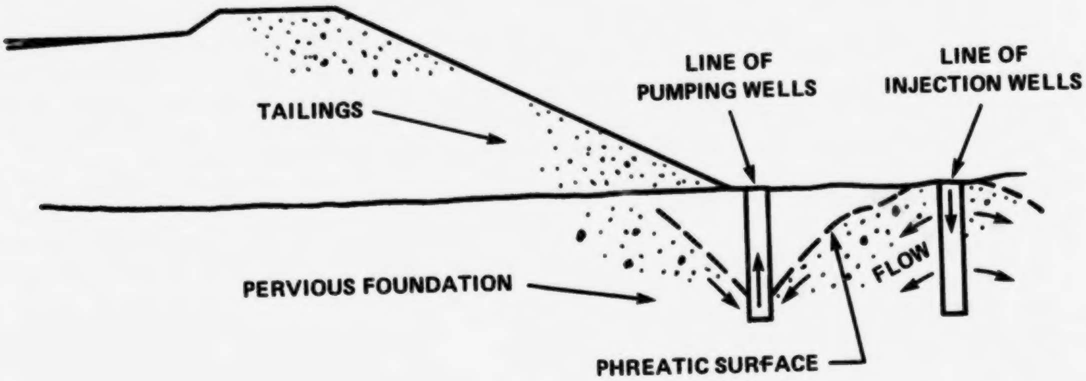
3.4.4.3 Hydraulic Barriers

Interceptor wells may be used in combination with a hydraulic barrier system established downgradient to the embankment, as shown in Figure 3-5. A hydraulic barrier system is usually made by installing a line of pumping wells downgradient to the leaking embankment, and a line of injection wells downgradient to the pumping wells. The injection wells supply fresh water, while the pumping wells extract ground water. Pump effluent is typically a mixture of native ground water, plume water, and injected fresh water. The use of hydraulic barriers is effective at sites where the subsurface is generally homogeneous. The use of hydraulic barriers is not a common practice in these segments, and their effectiveness must be demonstrated.

3.4.4.4 Grouting

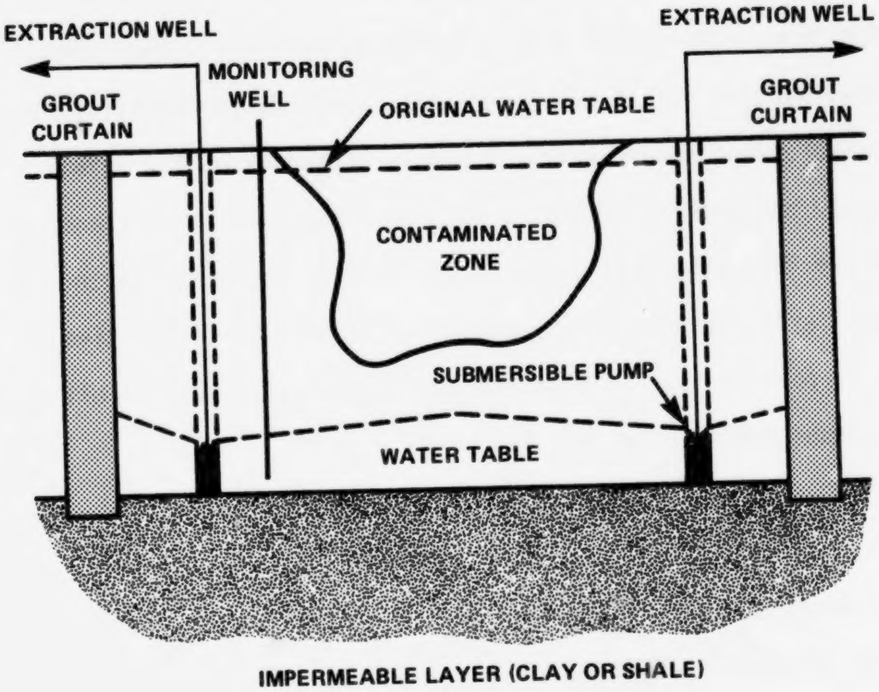
If a waste presents a serious pollution hazard to ground water, grouting the foundation rock may be warranted. The grouting process consists of pumping a fluid grout mixture (usually a water-cement compound) through drill holes into crevices and joints in rock to tighten the embankment foundation. Chemical grout is used to seal porous materials and cracks that are too small to accept a water-cement grout. Grouting must be thorough, because even a few ungrouted joints in permeable rock formations can render the grouting effort ineffective.[61]

Figure 3-6 illustrates a grout curtain being used in conjunction with extraction wells. This grouting process is often not very reliable, because it is difficult to ensure a completely impermeable grout curtain. Generally, grout curtains cannot be used to control deep vertical seepage within the curtain's boundaries. In some cases, grout curtains can reach depths of 60 meters; however, both the cost and unreliability of these systems increase rapidly at depths greater than 30 meters.[62]



Source: PEDCo Environmental, Inc. 1984

Figure 3-5 Hydraulic barrier for seepage collection



Source: PEDCo Environmental, Inc. 1984

Figure 3-6 Grout curtains and extraction wells for seepage control

3.4.4.5 Cutoff Walls

Cutoff walls are often used as seepage or ground-water pollution control systems because they are effective and relatively inexpensive. Sheet piling cutoff walls can extend 24-30 meters in depth, but they have a relatively short effective life (less than 20 years) and are difficult to construct to achieve a low permeability barrier. More effective cutoff walls can be constructed by digging narrow trenches to a depth of 9-15 meters and backfilling them, either with a soil-bentonite or a soil-cement-bentonite mixture that hardens into a homogeneous and very low-permeability barrier. The effective use of cutoff walls is highly dependent on the site's hydrogeologic properties, in that a naturally impermeable rock and/or soil must underlie the waste within the cost-effective trenching depth. If an impermeable layer does not exist, cutoff walls will be ineffective in stopping migration of pollutants. This technology is not applicable to all mines, and is not a common practice in this industry.

3.5 SUMMARY

Of the waste currently generated by the mining industry segments of concern, 56 percent is disposed of on site, 9 percent is backfilled, 31 percent may be considered to be utilized on site (principally in the leaching of copper dump wastes and in starter dams for tailings impoundments); and 4 percent is utilized off site (as fill and aggregate for road construction). Most tailings are disposed of in impoundments; but 5 percent are backfilled, and 2 percent are used off site (in construction, as soil supplements, etc.). Most mine water is recycled through the mill and used on site for other purposes (e.g., dust control) or treated and discharged. Few methods are available to reduce the amount of solid waste generated by mining and milling, but process modifications can reduce the water content and potential toxicity of these wastes. Many methods are available to design, site, maintain, and close disposal facilities in an environmentally acceptable manner. Commonly used mitigative measures include ground-water monitoring at leach operations only; and, for many types of operations, stabilization of waste, installation of some kind of cap, and revegetation during the closure phase. Available corrective action methods, not widely used in the mining industry, include interceptor wells, underground barriers to prevent the spread of contaminated ground water, and liners to contain the leachate.

SECTION 3 FOOTNOTES

[1] Tailings are often disposed of in ponds because, as described in Section 2, they leave the mill as a slurry.

[2] Greber et al. 1979.

[3] Charles River Associates 1985a.

[4] Vick 1981.

[5] Goodson and Associates 1982.

[6] Curtin 1983.

[7] Seitter and Hunt 1982.

[8] Seitter and Hunt 1982.

[9] Seitter and Hunt 1982.

[10] Charles River Associates 1985b.

[11] Schiller 1983.

[12] Heming 1984.

[13] PEDCo Environmental, Inc. 1984.

[14] USDA Forest Service 1979.

[15] PEDCo Environmental, Inc. 1984.

[16] Wixson et al. 1983.

[17] Seitter and Hunt 1982.

[18] A stope is an excavation from which ore has been mined in a series of steps.

[19] Vick 1981.

[20] Vick 1981.

[21] Goodson and Associates 1982.

[22] Klohn 1981.

SECTION 3 FOOTNOTES (Continued)

[23] Portfors 1981.

[24] Vick 1981.

[25] US EPA 1982a.

[26] Vick 1981.

[27] EPA 1982a.

[28] Vick 1981.

[29] PEDCo Environmental, Inc. 1984.

[30] Goodson and Associates 1982.

[31] PEDCo Environmental, Inc. 1984.

[32] TFI 1984.

[33] U.S. Nuclear Regulatory Commission 1983.

[34] BOM 1985.

[35] Geological Society of America 1971.

[36] U.S. Nuclear Regulatory Commision 1983.

[37] New Mexico Energy and Mining Department 1979.

[38] New Mexico Energy and Mining Department 1979.

[39] Pacific Northwest Laboratories 1983.

[40] BOM 1980b.

[41] Lucia 1982.

[42] Edwards et al. 1983.

[43] DOE 1985.

[44] DOE 1985.

[45] BOM 1980.

[46] U.S. Nuclear Regulatory Commission 1983.

[47] Lucia 1982.

[48] DOE 1985.

[49] DOE 1985.

[50] DOE 1985.

[51] DOE 1985.

[52] U.S. Nuclear Regulatory Commission 1983.

[53] DOE 1985.

[54] DOE 1985.

[55] Charles River Associates 1984.

[56] DOE 1985.

[57] U.S. Nuclear Regulatory Commission 1983.

[58] DOE 1985.

[59] U.S. Nuclear Regulatory Commission 1983.

[60] BOM 1985.

[61] BOM 1980b.

[62] Greber et al. 1979.

SECTION 4

POTENTIAL DANGER TO HUMAN HEALTH AND THE ENVIRONMENT

This section assesses the potential danger to human health and the environment associated with wastes generated by the mining industry. It identifies the hazardous chemical and physical characteristics of these wastes, estimates the amount and type of mining waste possessing these characteristics, describes mining waste damage case studies compiled by EPA, and discusses the effectiveness of mining waste management systems.

In this section, EPA is responding to the requirements of Sections 8002(f) and (p) of RCRA for analyses of the "potential dangers to human health and the environment from surface runoff of leachate," the "potential danger, if any, to human health and the environment from the disposal and reuse" of mining waste, and "documented cases in which danger to human health or the environment has been proved." Over a period of years, EPA has conducted these analyses with the support of consulting firms and individual experts.

The studies sponsored by EPA involved waste sampling at 86 mines in 22 states; chemical analyses of solid and liquid samples (and leachates from the solid samples); and monitoring of ground water at seven of eight representative sites (and surface water of five of the sites).

Reports on mining industry damage cases were obtained from state files and from information in EPA's files on sites on the National Priorities List for Superfund cleanup. The damage case analysis focused on the range and severity of contamination problems associated with mine and mill waste disposal at active, inactive, abandoned, and Superfund sites.

EPA is currently analyzing the amounts and rates of toxic releases from mine and mill wastes. This is an essential prerequisite to studies on exposures and effects, and is required for any quantification of risks to human health and the environment posed by these wastes.

4.1 WASTE CHARACTERISTICS CONSIDERED

Mining wastes may contain constituents, such as heavy metals, other toxic elements, radionuclides, cyanide compounds, and asbestos, that may be dangerous to human health and the environment. In addition, some mine wastes are corrosive (acidic) and others have a high potential for forming acid.

Table 4-1 presents the waste characteristics evaluated for this report, the criteria used to determine whether or not mining wastes have these characteristics, and the rationale for choosing these criteria. As the table indicates, EPA evaluated two general categories of waste characteristics for this report: RCRA Subtitle C Hazardous Waste Characteristics and Other Potentially Hazardous Characteristics. The following sections discuss the waste characteristics evaluated, the sampling methodology, and the sampling results obtained by EPA at selected mine sites.

To evaluate the hazardous characteristics of mining waste for this report, EPA's Office of Solid Waste (OSW) subdivided mining industry segments into the following mining region-commodity categories:

- New Mexico Uranium;
- Wyoming Uranium;
- Other Uranium;
- Florida Phosphate;
- Idaho Phosphate;
- Other Phosphate;

Table 4-1 Waste Characteristics, Hazard Criteria, and Bases for Criteria Used to Assess the Hazard Potential of Mining and Beneficiation Wastes

Waste characteristic	Hazard criterion	Basis for criterion
• RCRA Subtitle C Hazardous Waste Characteristics		
- Corrosivity	pH ≤2.0 or pH ≥12.5	40 CFR 261.22
- EP Toxicity	Metals in EP Extract:	40 CFR 261.24
	Mercury ≥0.2 mg/l Cadmium ≥1.0 mg/l Selenium ≥1.0 mg/l Silver ≥5.0 mg/l Arsenic ≥5.0 mg/l Chromium ≥5.0 mg/l Lead ≥5.0 mg/l Barium ≥100.0 mg/l	(100 times National Interim Primary Drinking Water Standards for Metals)
- Ignitability	(See definition used in 40 CFR 261.21)	40 CFR 261.21
- Reactivity	(See definition used in 40 CFR 261.23)	40 CFR 261.23
• Other Potentially Hazardous Characteristics		
- Cyanide	Cyanide ≥2 mg/l ≥10 mg/l ≥20 mg/l	(10, 50, and 100 times the Ambient Water Quality criterion for protection of human health, respectively)
- Radioactivity	Ra 226 ≥5 pCi/gm Ra 226 ≥20 pCi/gm	40 CFR Part 192 Derived from 40 CFR Part 192
- Asbestos	Asbestos content >1% by wt.	40 CFR Part 61
- Acid formation potential	Presence of metal sulfides and absence of carbonate minerals	Danger posed to the environment by acid drainage

Source: Compiled by EPA, OSW staff, 1985.

- Southwestern Copper;
- Other Copper;
- Western Lead/Zinc;
- Eastern Lead/Zinc;
- Missouri Lead/Zinc;
- Molybdenum;
- Nevada Gold/Silver;
- Other Gold/Silver;
- Taconite/Iron; and
- Tungsten.

EPA sampled at least one mine and mill in each of these categories for this study.[1] EPA then augmented this sample set by taking samples from operations (e.g., heap and dump leach operations) and industries (e.g., beryllium and rare earth metals) either not covered at all, or not sufficiently covered in the first sample set.[2] These results were then supplemented with data from a study performed for EPA's Effluent Guidelines Division (now the Industrial Technology Division) on the following mining industry segments: antimony, bauxite (aluminum), mercury, nickel, titanium, tungsten, and vanadium.[3] EPA's Industrial Environmental Research Laboratory performed the analyses of waste samples from mines in the asbestos mining industry. Generally, EPA sampled the full range of waste types (e.g., fresh tailings, mine water pond liquid and settled solids, tailings liquid and settled solids, pregnant and spent leach liquor (process liquors that may be characteristic of seepage from leach operations), and tailings dike material) produced by mining and beneficiation operations in these segments. The Agency also took additional samples of those wastes believed to be most likely to present a hazard to human health and the environment (e.g., heap and dump leach wastes). For this reason, the percentage of samples having hazardous or potentially hazardous characteristics is probably greater than would have been the case if a completely random sampling strategy had been used. However, the Agency excluded all results from samples that were believed to be either invalid or duplicative.

EPA's Office of Solid Waste planned the original sampling and analysis effort in 1979-1980 and, with the cooperation of the Office of Research and Development, took samples between 1979 and 1984. To show the scope of EPA's mining waste sampling and analysis effort, Table 4-2 presents 1980 figures for the number of active mines, the number of mines sampled, and the percent of mines sampled. Data are presented for 1980, because this was the year in which the sampling effort was planned and initiated. This table shows that EPA sampled 13 percent of all metal mines and 31 percent of all asbestos and phosphate mines active in 1980. Figure 4-1 is a map showing the locations of the mines EPA sampled.

4.1.1 RCRA Subtitle C Hazardous Waste Characteristics

Solid wastes are defined as hazardous under regulations implementing Subtitle C of RCRA if they exhibit any of four general characteristics: ignitability, corrosivity, reactivity, or EP toxicity. They are also considered hazardous if they are listed as hazardous in 40 CFR 261.31-261.33. Wastes may be listed under RCRA if the Administrator of EPA determines that the wastes meet one of the criteria in 40 CFR 261.11. The Administrator must indicate whether the wastes are ignitable, corrosive, reactive, EP toxic, acutely hazardous, or toxic (40 CFR 261.30). Since Congress has, at least temporarily, excluded mining wastes from regulation under Subtitle C of RCRA, EPA's current lists of hazardous wastes do not include wastes from mining and beneficiation processes.

Table 4-2 Scope of EPA's Mine Waste Sampling and Analysis Effort

Mining industry segment	Number of active mines in sector, 1980[a]	Number of active mines sampled	Percent of active mines sampled
Metals:			
Antimony	1	1	100
Bauxite (Aluminum)[b]	2	1	50
Beryllium	1	1	100
Copper	39	13	33
Gold[c]	44	6	14
Iron	35	5	14
Lead	33	4	12
Mercury	4	1	25
Molybdenum	11	3	27
Nickel	1	1	100
Rare earth metals	2	1	50
Silver	43	6	14
Titanium	5	2	40
Tungsten	29	1	3

Table 4-2 (continued)

Mining industry segment	Number of active mines in sector, 1980[a]	Number of active mines sampled	Percent of active mines sampled
Uranium	265	17	6
Vanadium	1	1	100
Zinc	20	7	35
Subtotal	536	71	13
Nonmetals:			
Asbestos	4	2	50
Phosphate	44	13	30
Subtotal	48	15	31
TOTAL	584	86	15

[a] Estimated by Bureau of Mines 1981 (BOM 1982).

[b] Although the BOM lists 10 active mines, there were ony two operations supplying bauxite for aluminum reduction. The other mines are supplying bauxite for other uses.

[c] Excludes placer mines.

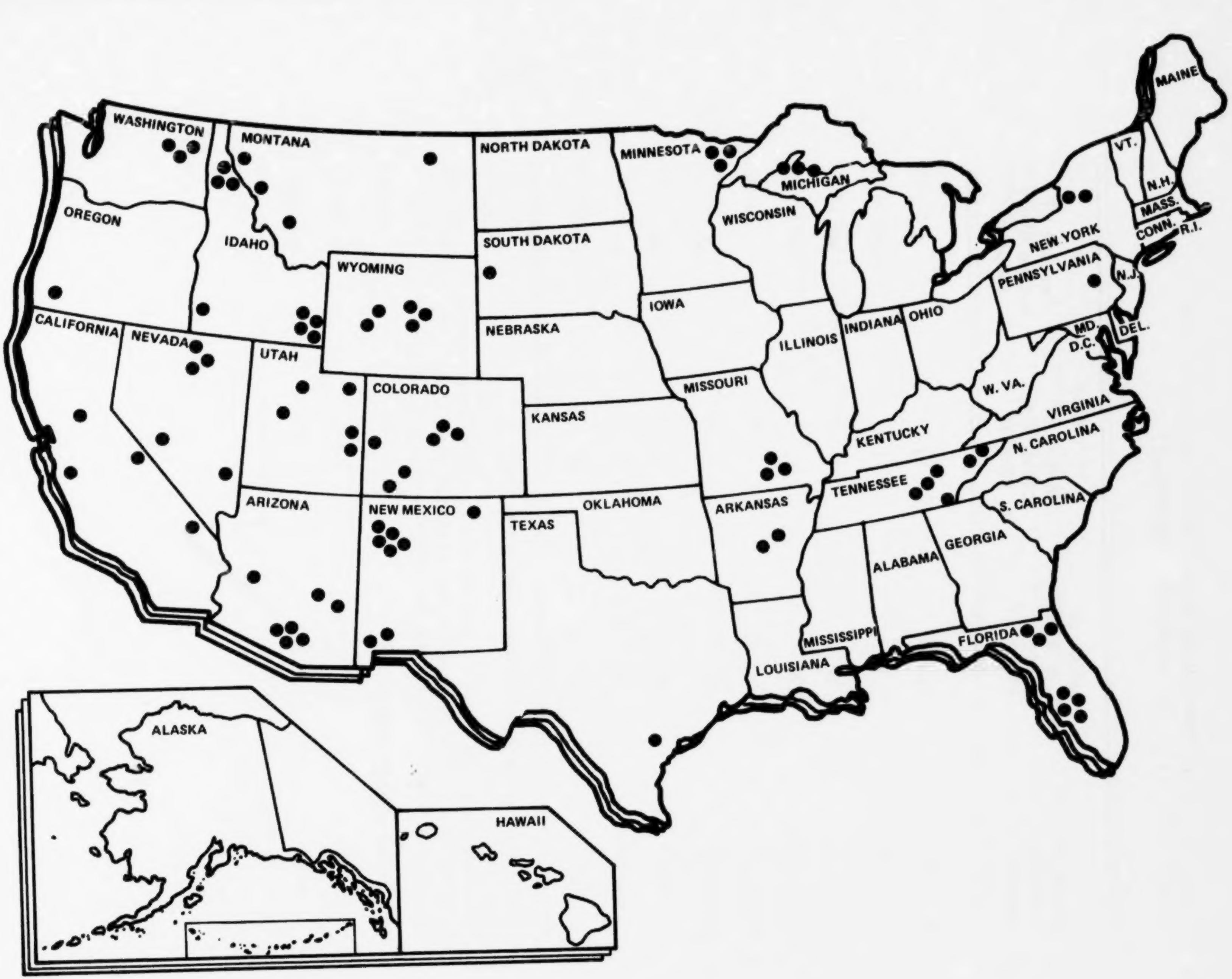


Figure 4-1. Approximate locations of mining/benefication sites active in 1980 sampled by EPA for this report

Mining wastes are far more likely to be corrosive or EP toxic than ignitable or reactive. Therefore, EPA did not evaluate ignitability, which measures the ability of wastes to cause or exacerbate fires, or reactivity, which measures explosivity and the ability of sulfide- or cyanide-containing wastes to generate toxic gases, vapors, or fumes, although some mining wastes containing cyanide or sulfide may be reactive. However, the toxic properties of cyanide-containing mining wastes were examined separately in this report.

The RCRA Subtitle C characteristics of corrosivity and EP toxicity are discussed below as they relate to mining and beneficiation wastes. In addition, copper dump leach, which may be a potential candidate for listing under 40 CFR 261.31 because of its potential EP toxicity and corrosivity, also is described.

4.1.1.1 Corrosivity

A waste is considered corrosive and therefore hazardous if it is a liquid and has a pH less than or equal to 2 or greater than or equal to 12.5, as determined by a pH meter.[4] EPA chose pH as a "barometer of corrosivity, because wastes exhibiting low or high pH can cause harm to human tissue, promote the migration of toxic contaminants from other wastes, and harm aquatic life" (45 FR 33109, May 19, 1980). The lower pH limit of 2.0 was chosen so that "a number of substances generally thought to be innocuous and many industrial wastewaters prior to neutralization" would not fall within the corrosive classification. The upper pH limit of 12.5 was chosen to exclude lime-stabilized wastes and sludges from corrosive classification (45 FR 33109, May 19, 1980). For this study, EPA also evaluated whether samples had a high pH (greater than 10 but less than 12.5) or low pH (greater than 2 but less than 4), to aid in deciding which wastes could be potential candidates for listing and which might cause damage to human health and the environment. These pH levels, and associated contamination by toxic metals, can degrade aquatic ecosystems.

Table 4-3 shows the results of the corrosivity analyses performed by EPA for this report. Of the 159 liquid waste samples taken by EPA, only 5 were corrosive. An additional 28 samples had low (more than 2 and less than 4) or high (more than 10 and less than 12.5) pH's. Some of the liquid samples, such as pregnant leach liquors or wastewater prior to treatment and discharge, are considered by industry to be process streams. The characteristics of some of these liquids would be likely to alter (improve) after the active life of the mine.

Table 4-4 identifies all of the industry segments that had at least one sample with a low or high pH. All copper dump leach operations had at least one sample with a pH less than or equal to 4 and 11 of the 23 liquid samples with pH's less than or equal to 4 were from the copper industry segment. Of the nine waste management operations having samples with pH's greater than 10, more than half were from tailings processed with caustic solutions. However, tailings such as these may later be treated to lower their pH, which reduces their hazard potential.

4.1.1.2 EP Toxicity

A solid waste is defined as EP toxic (and thus hazardous) if, using the test methods described in 40 CFR Part 261 (Appendix II), an extract from a representative sample of waste contains certain metals[5] at a concentration greater than or equal to 100 times the maximum contaminant levels for these metals as established by EPA's National Interim Primary Drinking Water

Table 4-3 Results of Corrosivity[a] Analyses of Liquid Mining Waste Samples

Mining industry segment	Number of samples analyzed	Number of samples with pH:				Number of samples corrosive[a]
		Less than or equal to 2[a]	Between 2 and 4[a]	Between 10 and 12.5[a]	Greater than or equal to 12.5[a]	
Metals:						
Copper	29	3 (10%)[c]	8 (29%)	3 (10%)	0	3 (10%)
Gold	5	0	0	1 (20%)	0	0
Iron	7	0	0	0	0	0
Lead	6	0	0	0	0	0
Molybdenum	9	0	1 (11%)	0	0	0
Silver	6	0	0	1 (17%)	0	0
Uranium	19	0	0	0	0	0
Zinc	15	0	0	0	0	0
Other metals[b]	47	1 (2%)	10 (21%)	4 (2%)	1 (2%)	2 (4%)
Subtotal	143	4 (3%)	19 (13%)	9 (6%)	1 (1%)	5 (3%)
Nonmetals:						
Asbestos	2	0	0	0	0	0
Phosphate	14	0	0	0	0	0
Subtotal	16	0	0	0	0	0
TOTAL	159	4 (3%)	19 (12%)	9 (6%)	1 (1%)	5 (3%)

[a] A waste is corrosive under current RCRA Subtitle C regulations if the pH is less than or equal to 2 or greater than or equal to 12.5

[b] Includes antimony, bauxite, beryllium, mercury, nickel, rare earth metals, titanium, tungsten, and vanadium.

[c] Numbers in parentheses are percentages of all samples analyzed for that industry segment that have the hazardous characteristic.

Source: PEDCo Environmental, Inc. 1984, ERCO 1984, and Harty and Terlecky 1982.

Table 4-4 Number of Mines, Wastes, and Operations with Samples Showing Low or High pH Levels

			Number of waste management operations with at least one sample:				
Mining industry segment	Type of waste management operation	Number of waste management operations analyzed	Having pH less than or equal to 2	Having pH between 2 and 4	Having pH between 10 and 12.5	Having pH greater than or equal to 12.5	Number of operations with corrosive waste[a]
Copper	No. mines involved[b]	13	3	5	1	0	3
	Mine waste[c]	7	0	3	0	0	0
	Dump leach	6	3	3	0	0	3
	Tailings	12	0	1	2	0	0
Gold	No. mines involved	5	0	0	1	0	0
	Mine waste	1	0	0	0	0	0
	Heap leach	2	0	0	1	0	0
	Tailings	2	0	0	1	0	0
Molybdenum	No. mines involved	3	0	1	0	0	0
	Mine waste	2	0	1	0	0	0
	Tailings	3	0	0	0	0	0
Silver	No. mines involved	5	0	0	1	0	0
	Mine waste	0	0	0	0	0	0
	Heap leach	0	0	0	0	0	0
	Tailings	5	0	0	1	0	0
Other metals[d]	No. mines involved	10	1	4	3	1	2
	Mine waste	5	0	2	0	0	0
	Dump/heap leach	1	0	0	1	0	0
	Tailings	7	1	2	2	1	2

Table 4-4 (continued)

Mining industry segment	Type of waste management operation	Number of waste management operations analyzed	Number of waste management operations with at least one sample:				
			Having pH less than or equal to 2	Having pH between 2 and 4	Having pH between 10 and 12.5	Having pH greater than or equal to 12.5	Number of operations with corrosive waste[a]
Total (All segments)	No. mines involved	78	4	10	8	1	5
	Mine waste	43	0	6	0	0	0
	Dump/Heap leach	10	3	3	1	0	3
	Tailings	52	1	3	7	1	2

[a] A waste is corrosive only if its pH is less than or equal to 2 or greater than or equal to 12.5.

[b] The number of mines involved may be less than the sum of sampled operations if one mine has more than one operation; for example, the same mine site might have both mine waste and one or more leach operations.

[c] Mine waste includes mine water.

[d] Includes antimony, bauxite, beryllium, mercury, nickel, rare earth metals, titanium, tungsten, and vanadium.

Source: PEDCo Environmental, Inc. 1984, ERCO 1984, and Harty and Terlecky 1982.

Standards (NIPDWS) (40 CFR Part 141). EP toxic levels are:

- Mercury (Hg) ≥0.2 mg/l;
- Cadmium (Cd) or selenium (Se) ≥1.0 mg/l;
- Silver (Ag), arsenic (As), total chromium (Cr), or lead (Pb) ≥5.0 mg/l; and,
- Barium (Ba) ≥100 mg/l.

EPA designed the EP toxicity test to simulate the leaching of hazardous constituents from a sanitary landfill into ground water. It approximates the conditions prevalent within a landfill where weak organic acids may come in contact with toxic metals. In recognition of the fact that contaminant concentration levels would decrease between the point at which the leachate migrates from the waste and the point of human or environmental exposure, EPA set EP toxicity levels for contaminants in leachate at 100 times the levels acceptable in drinking water. An attenuation factor of 100 was used rather than a lower level (e.g., 10 times the drinking water limit) because of the lack of empirical data on which to base an attenuation factor, the absence of a variance procedure (i.e., delisting) for wastes that fail the EP test, and because "EPA believes the...[extraction procedure] to be a somewhat less precise instrument than the listing mechanism for determining hazard, inasmuch as the EP fails to take into account factors such as the concentration of toxicants in the waste itself and the quantity of waste generated which would have a bearing on the hazardousness of the waste" (45 FR 33111, May 19, 1980). EPA preferred therefore to "entrust determinations of marginal hazard to the listing mechanism rather than to the EP" (45 FR 33111, May 19, 1980). In adopting the 100-fold attenuation factor, the Agency explained that "anything which fails the EP at this factor has the potential to present a substantial hazard regardless of the attenuation mechanisms at play" (45 FR 33111, May 19, 1980).

The metals measured by RCRA's EP toxicity test can, however, cause some types of environmental damage at levels much lower than those that fail RCRA's EP toxicity test or even EPA's National Interim Primary Drinking Water Standards, especially if these metals are contained in wastes that contaminate surface water rather than ground water. Accordingly, the 24-hour average level of EP metals set by EPA's Ambient Water Quality Criteria for the Protection of Aquatic Life are, in all cases, lower than those permitted by EPA's drinking water standards, and therefore are much lower than the levels allowed by RCRA's EP toxicity test. This does not mean that all mining wastes meeting the EP toxicity test pose a threat to aquatic life, because the EP leaching procedure was designed to evaluate the potential of a given waste for unacceptable degradation of ground water and assumed that the wastes would be disposed of above an aquifer supplying drinking water (a conservative assumption). Table C-1 in Appendix C of this report provides a comparison of EP toxicity levels, drinking water levels, and ambient water quality levels for the metals measured by the EP toxicity test. Research findings on the levels of metals measured by the EP toxicity test (i.e., arsenic, cadmium, chromium, lead, mercury, and selenium) that are toxic to aquatic biota are summarized in Tables C-2 to C-7 of Appendix C.

EPA's sampling results indicate that a small percentage of the mining waste samples were EP toxic. Of the 332 samples from the metals mining industry segments, 21 (6 percent) exhibited the characteristic of EP toxicity. These 21 samples were from the copper, gold, lead, silver, zinc, and other metals industry segments. An additional 39 samples had elevated levels (i.e., between 20 and 100 times the levels permitted by the drinking water standards) of the metals measured by the EP toxicity test; these additional samples came from these same industry segments and from the uranium and phosphate mining segments. These results are summarized in Table 4-5.

Tables 4-6 and 4-7 differentiate EP toxicity test results for solid samples and liquid samples, respectively. Twenty of the 21 EP toxic samples were solid samples and 31 of the 39 samples with elevated levels (i.e., between 20 and 100 times the levels permitted in the drinking water standards) of the metals measured by the EP toxicity test were solid samples. One liquid sample was EP toxic, and it was from the copper industry segment.

Table 4-8 identifies all industry segments that had at least one EP toxic sample or one sample with an elevated level of one of the metals measured by the EP toxicity test. Samples from 86 mines were tested for EP toxicity. At least one sample from 10 of these mines was EP toxic, and 29 mines had at least one sample with an elevated level (i.e. greater than 20 times the NIPDWS) of an EP toxic metal. A particularly high percentage of samples from gold heap leach and tailings, lead mine waste and tailings, zinc tailings, and copper dump leach operations had EP toxic or elevated levels of one of the metals measured by the EP toxicity test. Four of the eight copper dump leach operations, three of the seven zinc tailings operations, four of the six gold tailings operations, two of the three gold heap leach operations, and five of the six lead operations had at least one sample with a level of one of the metals measured by the EP toxicity test greater than or equal to 20 times the NIPDWS.

Table 4-5 Results of EP Toxicity Analyses for All Samples

Mining industry segment	Number of samples analyzed	Number of samples with at least one EP toxic metal at level between 20 and 100X the NIPDWS[a]	Number of samples EP toxic[a]
Metals:			
Copper	83	4 (5%)	1 (1%)
Gold	26	7 (27%)	3 (12%)
Iron	31	0	0
Lead	15	4 (27%)	6 (40%)
Molybdenum	15	0	0
Silver	25	3 (12%)	4 (16%)
Uranium	67	5 (7%)	0
Zinc	25	5 (20%)	4 (16%)
Other metals[b]	45	8 (18%)	3 (7%)
Subtotal	332	36 (11%)	21 (6%)
Nonmetals:			
Asbestos	7	0	0
Phosphate	70	3 (4%)	0
Subtotal	77	3	0
TOTAL	409	39 (10%)	21 (5%)

[a] Numbers in parentheses are percentages of all samples analyzed for that industry segment that had the hazardous characteristic.

[b] Includes antimony, bauxite, beryllium, mercury, nickel, rare earth metals, titanium, tungsten, and vanadium.

Source: PEDCo Environmental, Inc. 1984, ERCO 1984, and Harty and Terlecky 1982.

Table 4-6 Results of EP Toxicity Analyses for Solid Samples

Mining industry segment	Number of samples analyzed	Number of samples with at least one EP toxic metal at level between 20 and 100X the NIPDWS[a]	Number of samples EP toxic[a]
Metals:			
Copper	72	1 (1%)	0
Gold	22	4 (18%)	3 (14%)
Iron	30	0	0
Lead	14	4 (29%)	6 (43%)
Molybdenum	14	0	0
Silver	22	3 (14%)	4 (18%)
Uranium	63	5 (8%)	0
Zinc	22	5 (23%)	4 (18%)
Other metals[b]	39	6 (15%)	3 (8%)
Subtotal	298	28 (9%)	20 (7%)
Nonmetals:			
Asbestos	5	0	0
Phosphate	68	3 (4%)	0
Subtotal	73	3 (4%)	0
TOTAL	371	31 (8%)	20 (5%)

[a] Numbers in parentheses are percentages of all samples analyzed for that industry segment that had the hazardous characteristic.

[b] Includes antimony, bauxite, beryllium, mercury, nickel, rare earth metals, titanium, tungsten, and vanadium.

Source: PEDCo Environmental, Inc. 1984, ERCO 1984, and Harty and Terlecky 1982.

Table 4-7 Results of EP Toxicity Analyses for Liquid Samples

Mining industry segment	Number of samples analyzed	Number of samples with at least one EP toxic metal at level between 20 and 100X the NIPDWS[a]	Number of samples EP toxic[a]
Metals:			
Copper	11	3 (27%)	1 (9%)
Gold	4	3 (75%)	0
Iron	1	0	0
Lead	1	0	0
Molybdenum	1	0	0
Silver	3	0	0
Uranium	4	0	0
Zinc	3	0	0
Other metals[a]	6	2 (33%)	0
Subtotal	34	8 (24%)	1 (3%)
Nonmetals:			
Asbestos	2	0	0
Phosphate	2	0	0
Subtotal	4	0	0
TOTAL	38	8 (21%)	1 (3%)

[a] Numbers in parentheses are percentages of all samples analyzed for that industry segment that had the hazardous characteristic.

[b] Includes antimony, bauxite, beryllium, mercury, nickel, rare earth metals, titanium, tungsten, and vanadium.

Source: ERCO 1984 and Harty and Terlecky 1982.

Table 4-8 Number of Mines and Waste Management Operations with EP Toxic Samples or Samples Having Elevated Levels of Metals, as Measured by the EP Toxicity Test

Mining industry segment	Type of waste management operation	Number of operations analyzed	Number of operations with at least one EP toxic sample (100X NIPDWS)	Number of operations with at least one sample between 20 and 100X NIPDWS[a]	Number of operations with at least one sample greater than 20X the NIPDWS[b]
Copper	No. mines involved	13	1	3	4
	Mine waste	11	0	0	0
	Dump leach	8	1	3	4
	Tailings	13	0	0	0
Gold	No. mines involved	6	2	5	5
	Mine waste	6	1	0	1
	Heap leach	3	0	2	2
	Tailings	6	2	3	4
Lead	No. mines involved	4	3	2	3
	Mine waste	2	1	1	2
	Tailings	4	2	2	3
Phosphate	No. mines involved	13	0	3	3
	Mine waste	13	0	1	1
	Tailings	10	0	2	2
Silver	No. mines involved	6	1	2	2
	Mine waste	4	1	1	1
	Heap leach	0	0	0	0
	Tailings	6	1	1	2

Table 4-8 (continued)

Mining industry segment	Type of waste management operation	Number of operations analyzed	Number of operations with at least one EP toxic sample (100X NIPDWS)	Number of operations with at least one sample between 20 and 100X NIPDWS[a]	Number of operations with at least one sample greater than 20X the NIPDWS[b]
Uranium	No. mines involved	17	0	5	5
	Mine waste	17	0	5	5
	Tailings	NA	NA	NA	NA
Zinc	No. mines involved	7	2	3	3
	Mine waste	5	0	1	1
	Tailings	7	2	3	3
Other Metals[c]	No. mines involved	10	1	5	5
	Mine waste	7	1	2	2
	Tailings	9	1	3	4
TOTAL (All segments)	No. mines involved	86	10	28	29
	Mine waste	75	4	11	13
	Dump/Heap leach	11	1	5	6
	Tailings	65	8	14	18

NA indicates not applicable to this report.

[a] Samples were not EP toxic but had elevated levels of EP toxic metals.

[b] Samples were EP toxic or had elevated levels of EP toxic metals; results in this column may not equal the sum of results in the previous two columns because samples were often tested for more than one EP toxic metal.

[c] Includes antimony, bauxite, beryllium, mercury, nickel, rare earth metals, titanium, tungsten and vanadium.

Source: PEDCo Environmental, Inc. 1984, ERCO 1984, and Harty and Terlecky 1982.

Table 4-9 shows the number and percentage of EP toxic samples and the number of samples having elevated levels of the metals measured by the EP toxicity test, by type of metal. Nineteen of the 21 samples failing the standard EP toxicity test failed because they had EP toxic levels of lead; in addition, 15 of the 39 samples with elevated levels of metals measured by the EP toxicity test had elevated levels of lead.

For purposes of comparison with these EP toxicity test results, most mine waste samples, most settled solid samples, and some low-grade ore samples were subjected to a modified EP toxicity test in which deionized water, rather than acetic acid, was used as the extracting medium. None of the 214 samples subjected to this test produced leachates containing metal concentrations at the EP toxic level, including the samples from the lead industry. These modified EP test results show that in at least some mining waste situations, lead and other toxic metal constituents may not be mobilized. Actual leachate samples were usually not obtained, and therefore actual leachate concentrations are unknown.

Since sulfuric acid simulates the situation in which waste leaches into an acidic environment more closely than does acetic acid, sulfuric acid might be an appropriate test leaching medium for modeling such an environment. For example, when lead combines with sulfuric acid, the lead sulfate that is formed precipitates out of the solution, which renders the lead less soluble than it would be if it were combined with acetic acid. The results from EPA's modified EP toxicity test using deionized water, and information on the fate of some waste constituents in acidic environments, suggest that additional toxicity tests may be necessary to simulate the potential hazard posed by some mining wastes in some environments.

Table 4-9 Number and Percentage of EP Toxic Samples and Samples Having Elevated Levels of Metals Measured by the EP Toxicity Test, by Type of Metal

EP toxic metals	Number of samples EP toxic (100X NIPDWS)[a]	Percentage of all EP toxic samples[a]	Number of samples with elevated levels of EP toxic metals (greater than 20 and less than 100X NIPDWS)[b]	Percentage of all samples with elevated levels of metals (greater than 20 and less than 100X NIPDWS)[b]
Arsenic	1	5	3	8
Barium	0	0	2	5
Cadmium	1	5	6	15
Chromium	0	0	3	8
Lead	19	86	15	38
Mercury	1	5	8	21
Silver	0	0	0	0
Selenium	0	0	6	15

[a] Twenty-one samples were EP toxic. However, one of these samples had EP toxic levels of two of the metals measured by the EP toxicity test.

[b] Thirty-nine samples contained metals measured by the EP toxicity test at levels between 20 and 100 times the NIPDWS. Many of these samples contained these levels for more than one of the metals.

Source: PEDCo Environmental Inc. 1984, ERCO 1984, Harty and Terlecky 1982.

4.1.1.3 EP Toxicity and Corrosivity (Copper Dump Leach Liquor)

In the case of dump leach liquor from copper dump leach operations, EPA believes that the results of the sampling and analyses performed on these samples and presented in Table 4-10 indicate that this waste may be a potential candidate for listing because of its acidity and relatively high concentrations of toxic metals. Partial results for samples of this waste were presented in Tables 4-3 and 4-4 (Results of Corrosivity Analyses) and Tables 4-5, 4-7, and 4-8 (Results of EP Toxicity Tests).

As shown in Table 4-10, the sample from leach operation no. 1 was EP toxic, with an arsenic level of 7.8 mg/l (156 times the NIPDWS) and a cadmium level of 1.8 mg/l (180 times the NIPDWS). Samples from all three leach operations had arsenic and cadmium levels at least 50 times their respective NIPDWS limits. Samples from two of the three operations had levels of chromium and selenium greater than 20 times the NIPDWS. Two of the three copper dump leach samples were corrosive, with pH's of less than 2, and the sample from the third site had a very low pH (2.49).

4.1.2 Other Characteristics

The other criteria used in this report to assess the potential hazard of mining waste include properties such as radioactivity and acid formation potential, and the presence at certain levels of hazardous constituents such as cyanide or asbestos. These constituents and properties are considered to be potentially hazardous because they are believed to pose a threat to human health and the environment if they are present in waste, including mining waste, at the levels specified below.

4.1.2.1 Cyanide

For the purpose of this report, EPA assessed liquid mining waste samples in relation to various cyanide levels: greater than or equal to 2 mg/l,

Table 4-10 Results of Corrosivity and EP Toxicity Analyses of Copper Dump Leach Liquor Samples

Tested characteristic	Sample from leach operation no. 1 (mg/l)	Sample from leach operation no. 2 (mg/l)	Sample from leach operation no. 3 (mg/l)
pH	1.82	1.95	2.49
Arsenic mg/l	7.8 (156 X NIPDWS[a])	3.5 (70 X NIPDWS)	2.5 (50 X NIPDWS)
Barium mg/l	--[b]	--	--
Cadmium mg/l	1.8 (180 X NIPDWS)	0.82 (82 X NIPDWS)	0.55 (55 X NIPDWS)
Chromium mg/l	3.4 (68 X NIPDWS)	1.2 (24 X NIPDWS)	0.81 (16 X NIPDWS)
Lead mg/l	--	--	--
Mercury mg/l	--	--	--
Selenium mg/l	0.57 (57 X NIPDWS)	0.35 (35 X NIPDWS)	-- --
Silver mg/l	-- --	-- --	0.13 (3 X NIPDWS)

[a] National Interim Primary Drinking Water Standards.

[b] Dash (--) indicates level of this metal was less than the NIPDWS limit.

Source: ERCO 1984.

greater than or equal to 10 mg/l, and greater than or equal to 20 mg/l. These levels are 10, 50, and 100 times, respectively, the ambient water quality (AWQ) criterion for cyanide for the protection of human health (assuming daily ingestion of 2 liters of contaminated drinking water and 6.5 grams of tissue from organisms living in the same contaminated water). In the cost analysis section of this report, EPA used a cyanide level of greater than or equal to 10 mg/l to define the threshold of hazard. (No samples from the iron, uranium, other metals, asbestos, or phosphate industry segments were analyzed for cyanide, because cyanide is not introduced into mining and beneficiation processes in these industries.)

Because of the difficulty of analyzing waste samples for cyanide, EPA had several laboratories test several of the cyanide samples. Table 4-11 shows the results of cyanide analyses of liquid waste samples. Of 27 liquid samples analyzed for cyanide, 8 samples (30 percent) had at least one test result showing cyanide concentrations greater than or equal to 2.0 mg/l: seven of the samples were from the gold industry segment, and one sample was from the copper segment.

All of the cyanide sample test results for which at least one test showed a cyanide level greater than or equal to 2.0 mg/l are presented in Table 4-12. As shown on this table, the copper tailings pond sample had a cyanide level between 2 and 10 mg/l, and three of the five gold tailings pond samples had a cyanide level of at least 10 mg/l (and one of these three gold tailings samples had a cyanide level of at least 20 mg/l). Both samples from gold heap leach operations had cyanide levels greater than 10 mg/l.

EPA believes that wastes from gold and silver metal recovery and heap leach operations may be potential candidates for listing, because of their tendency to contain high levels of cyanide. Although EPA did not take any

Table 4-11 Results of Cyanide Analyses of Liquid Waste Samples

Mining industry segment	Number of samples analyzed	Number of samples with at least one test result showing CN greater than 2 mg/l[a] (10X AWQ)
Metals:		
Copper	13	1 (8)
Gold	7	7 (100)
Lead	3	0
Molybdenum	3	0
Zinc	1	0
TOTAL	27	8 (30)

[a] Numbers in parentheses are percentage of samples taken in that industry segment having the potentially hazardous characteristic.

Source: Personal Communication from PEDCo Environmental, Inc. 1984; ERCO 1984.

Table 4-12 Summary of Cyanide Sampling Results for Liquid Samples with at Least One Test Result Greater than 2 mg/1

Type of mine, operation, and sample identification	Number of tests	Number of tests with CN values less than 2 mg/1	Number of tests with CN values between 2 and 10 mg/1	Number of tests with CN values between 10 and 20 mg/1	Number of tests with CN values greater than or equal to 20 mg/1
Copper mine					
Tailings pond					
Sample A	1		1		
Gold mine 1					
Tailings pond					
Sample A	3	1	2		
Sample B	4			3	1
Gold mine 2					
Tailings pond					
Sample A	4		3		1
Sample B	5				5
Gold mine 3					
Tailings pond					
Sample A	1			1	
Gold mine 4					
Barren leach pond					
Sample A	1				1
Gold mine 5					
Pregnant heap leach					
Sample A	1			1	

Source: Personal communication from PEDCo Environmental, Inc. 1984; ERCO 1984.

samples of silver heap leach operations specifically, the similarity of gold and silver heap leach operations makes it likely that silver heap leach wastes also have high levels of cyanide. With few exceptions, gold and silver values that are leached are extracted from finely crushed ores, concentrates, tailings, and low-grade mine rock by dilute and weakly alkaline solutions of potassium cyanide or sodium cyanide.[6]

In analyses performed to support the promulgation of effluent limitations guidelines and standards for the ore mining and dressing point source category (i.e., metals mining and beneficiation), EPA's Effluent Guidelines Division (now the Industrial Technology Division) found that 2 of 68 mill wastewater samples tested for cyanide from the copper/lead/zinc/gold/silver/platinum/molybdenum industrial subcategory had cyanide levels greater than 2 mg/l but less than 10 mg/l.[7] But these were influent samples (to treatment) and would be treated prior to discharge. The highest discharge level, even without adequate treatment, was 0.4 mg of total cyanide per liter. Free cyanide was not measured.

Cyanide is an environmental hazard at levels significantly lower than 2 mg/l (EPA's Cyanide Ambient Water Quality Criteria for the protection of human health). The 24-hour average level of cyanide allowed by EPA's Ambient Water Quality Criteria for the protection of freshwater aquatic life is 0.0035 mg/l, with the concentration not to exceed 0.052 mg/l at any time (45 FR 79331; November 20, 1980). Table C-8 in Appendix C summarizes research findings on the toxicity of cyanide to aquatic biota.

4.1.2.2 Radioactivity

Naturally occurring radionuclides in mining waste and ore may pose a radiation hazard to human health if the waste is used in construction or land reclamation or if concentrations of radionuclides (e.g., radium-226) are high enough to produce significant concentrations of hazardous decay products (e.g., radon-222).

Two criteria have been used in this report to assess potentially hazardous levels of radioactivity in mining waste. These criteria are both based on EPA's Standards for Protection Against Uranium Mill Tailings (40 CFR Part 192). These regulations contain a "cleanup" standard for uranium mill tailings that is set at a limit of 5 pCi of radium-226 per gram for the first 15 centimeters of soil below the surface. (The 5 pCi/g radioactivity criterion was also chosen by EPA in an Advance Notice of Proposed Rulemaking published in 1978 (43 FR 59022) that solicited comments on expanding the list of RCRA hazardous waste characteristics to include a "radioactivity charcteristic".) The second radioactivity criterion used in this report, 20 pCi or more of radium-226, is based on the "disposal design" portion of the same standard, which requires that the average release rate of radon-222 not exceed 20 pCi per square meter per second. In this report, EPA made the conservative assumption that each picocurie of radium-226 per gram of waste produces an average release rate of 1 pCi of radon-222 per square meter per second. As a result, a radioactivity criterion of 20 pCi or more of radium-226 per gram of waste can be assumed to include all wastes that would fail to meet the radon-222 criterion set forth in 40 CFR Part 192.

EPA analyzed selected mining wastes to determine their radium-226 concentrations. Of 187 solid waste samples, 69 (37 percent) had radium-226 concentrations greater than or equal to 5 pCi/g. These samples were from the uranium, "other" metals, and phosphate mining segments. Of the same 187 samples, 34 (18 percent) had radium-226 concentrations greater than or equal to 20 pCi/g; these samples were also from the uranium, other metals group, and phosphate mining industry segments. Results of the radium-226 analyses are presented in Table 4-13. (Asbestos samples were not tested for radioactivity, because EPA believed that wastes from this industry segment were unlikely to be radioactive.)

The number of mines and waste management operations having radioactive samples is presented in Table 4-14. All 17 uranium mines sampled by EPA had at least one mine waste sample with a level of radium-226 greater than or equal to 5 pCi/g. Fourteen of the 17 mines had at least one mine waste sample of radium-226 greater than or equal to 20 pCi/g. Ten of the 13 phosphate mines sampled by EPA had at least one sample with a level of radium-226 greater than or equal to 5 pCi/g. Only 2 of these mines, however, had samples with levels of radium-226 greater than or equal to 20 pCi/g. Two of the three other metals mines sampled had at least one sample with a level of radium-226 greater than or equal to 5 pCi/g. Only one of these mines, however, had a sample with a radium-226 level greater than or equal to 20 pCi/g.

Much of the available scientific literature concerned with radiation effects on organisms focuses on human health; information on these radiation effects is summarized in Table C-9 of Appendix C.

4.1.2.3 Asbestos

EPA chose to evaluate asbestos as a potentially hazardous mining waste constituent because of the well-documented inhalation danger that asbestos fibers, even in very small quantities, pose to human health. The health effects of asbestos exposure and the rationale for the level of asbestos considered in this report to be potentially hazardous are described below.

Table 4-13 Results of Radioactivity Analyses of Solid Waste Samples

Mining industry segment	Number of samples analyzed	Number of samples with Ra-226 levels greater than or equal to 5 pCi/g[b]	Number of samples with Ra-226 levels greater than or equal to 20 pCi/g[b]
Metals:			
Copper	17	0	0
Gold	4	0	0
Iron	8	0	0
Lead	4	0	0
Molybdenum	6	0	0
Silver	6	0	0
Uranium	58	40 (69%)	29 (50%)
Zinc	10	0	0
Other metals[a]	7	5 (71%)	2 (29%)
Subtotal	120	45 (38%)	31 (26%)
Nonmetals:			
Phosphate	67	24 (36%)	3 (4%)
TOTAL	187	69 (37%)	34 (18%)

[a] Includes antimony, bauxite, beryllium, mercury, nickel, rare earth metals, titanium, tungsten, and vanadium.

[b] Numbers in parentheses show percentage of samples taken in that industry segment having the potentially hazardous characteristic.

Sources: PEDCo Environmental, Inc. 1984, ERCO 1984, and Harty and Terlecky 1982.

Table 4-14 Number of Waste Management Operations Having Radioactive Samples

Mining industry segment	Type of waste management operation	Number of operations sampled	Number of operations with at least one sample with level of Ra-226 greater than or equal to 5 pCi/g	Number of operations with at least one sample with level of Ra-226 greater than or equal to 20 pCi/g
Uranium	No. mines involved	17	17	14
	Mine waste	17	17	14
Phosphate	No. mines involved	13	10	2
	Mine waste	13	8	0
	Tailings	10	6	2
Other metals[a]	No. mines involved	3	2	1
	Mine waste	2	2	1
	Tailings	3	2	1
Total	No. mines involved	62	29	17
	Mine waste	55	27	15
	Heap/dump leach	2	0	0
	Tailings	41	8	3

[a] Includes antimony, bauxite, beryllium, mercury, nickel, rare earth metals, titanium, tungsten, and vanadium.

Source: PEDCo Environmental, Inc. 1984 and ERCO 1984.

According to the 1982 EPA Support Document for the Final Rule on Friable Asbestos-Containing Materials in School Buildings, "the hazards of asbestos exposure identified by epidemiologic research are cancers of the lung, pleura, peritoneum, larynx, pharynx and oral cavity, esophagus, stomach, colon and rectum, and kidney. Inhalation of asbestos fibers also produces a non-cancerous lung disease, asbestosis." Pleural and peritoneal mesotheliomas (cancers) are considered "signature" diseases for asbestos exposure; that is, these diseases are almost always caused by asbestos exposure. There are well-documented cases of mesotheliomas occurring in persons residing within a mile of an asbestos mine who had no other known asbestos exposure.[8]

EPA has promulgated a National Emission Standard for asbestos (40 CFR Part 61, Subpart M) under Section 112 of the Clean Air Act, establishing asbestos disposal requirements for active and inactive disposal sites. The regulation requires owners and operators of demolition and renovation projects to follow specific procedures to prevent asbestos emissions to the outside air, and further requires that demolition and renovation material be controlled if the material contains more than 1 percent asbestos by weight in a form that "hand pressure can crumble, pulverize, or reduce to powder when dry." In this report, the Agency used this 1 percent criterion to determine when mining wastes should be considered potentially hazardous on the basis of their asbestos content.

Only five waste samples obtained from asbestos mining and milling sites were analyzed for asbestos. The results of these analyses, shown in Table 4-15, indicate that the asbestos content of all of these samples greatly exceeded 1 percent.

Table 4-15 Results of Asbestos Analyses

Sample number	Type of asbestos	Estimated percentage asbestos by weight
1	Chrysotile	20-40
2	Chrysotile	5-20
3	Chrysotile	70-85
4	Chrysotile	30-50
5	Chrysotile	70-90

Source: Based on analyses performed by the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Regulations in Subpart M of 40 CFR Part 61 also contain standards for emissions from asbestos mills and active and inactive asbestos waste disposal sites. According to these regulations, owners and operators of asbestos mills must ensure that their facilities either discharge no visible emissions to the outside air, or use air cleaning devices to clean emissions as specified in 40 CFR 61.154. Owners and operators of active asbestos waste disposal sites must ensure that no visible asbestos emissions are discharged to the outside air, cover asbestos-containing waste material at least once a day, or receive approval from the Administrator of EPA to use alternate control measures. The regulation also requires security measures for active and inactive asbestos waste disposal sites.

There is evidence that asbestos is present in many of the wastes generated by the metals mining industry segments covered in this report. Asbestiform amphibole fibers from taconite mill tailings were detected at high concentrations (14-644 million fibers per liter) in Lake Superior.[9] Sampling performed by EPA's Effluent Guidelines Division to develop effluent limitations guidelines and standards for the ore mining and dressing point source category showed that asbestos fibers were present in mine or mill water from almost all metals mining industry segments.[10] Based on these results and on a statistical comparison with the suspended solids data, EPA found that by controlling the suspended solids in the discharge, the asbestiform fiber concentrations were effectively controlled in this industry.

Some effects of asbestos exposure, such as toxicity, bioaccumulation, cytotoxicity, asbestosis, and carcinogenicity on humans, bacteria, aquatic biota, and rats are summarized in Table C-10 in Appendix C.

4.1.2.4 Acid Formation Potential

The exposure and subsequent oxidation of naturally occurring metal sulfides (especially iron pyrite) in ores and mining waste can produce acid, which may increase the leaching and mobility of toxic waste constituents, including the heavy metals. Wastes that contain significant amounts of iron pyrites (FeS_2) or other base metal sulfides may release acids and metals for many decades. The hazard is initiated by the chemical reaction of air, water, pyrite, and pyrrhotite or other iron-bearing sulfides to produce sulfuric acid:

$$4FeS_2 + 15\,O_2 + 14H_2O \longrightarrow 4Fe(OH)_3\downarrow + 8H_2SO_4$$

For example, the oxidation of the pyrite in 1 ton of waste having a 1 percent pyritic sulfur content would produce 15 kilograms of sulfuric acid. Unless the acid is neutralized (by the alkalinity of the water or by reaction with carbonate material in the waste), the acid will reduce the pH of the water and increase the concentration of the potentially toxic waste constituents, especially metals, that are leached and transported.

The potential effect of acid drainage on the concentration of metals in leachate is illustrated in Figure 4-2. For example, at a pH of 5.5, the free metal ion concentration in equilibrium with solid oxides or hydroxides of mercury (Hg) is approximately 0.0002 mg/l. If enough acid is added to the water to reduce the pH from 5.5 to 4.5, the concentration of mercury increases to more than 0.02 mg/l, an increase of more than two orders of magnitude. Although the diagram is an oversimplification and does not reflect the complexities of the real world, it does demonstrate that acid may greatly increase the concentration of metals in leachate and exacerbate environmental hazards.

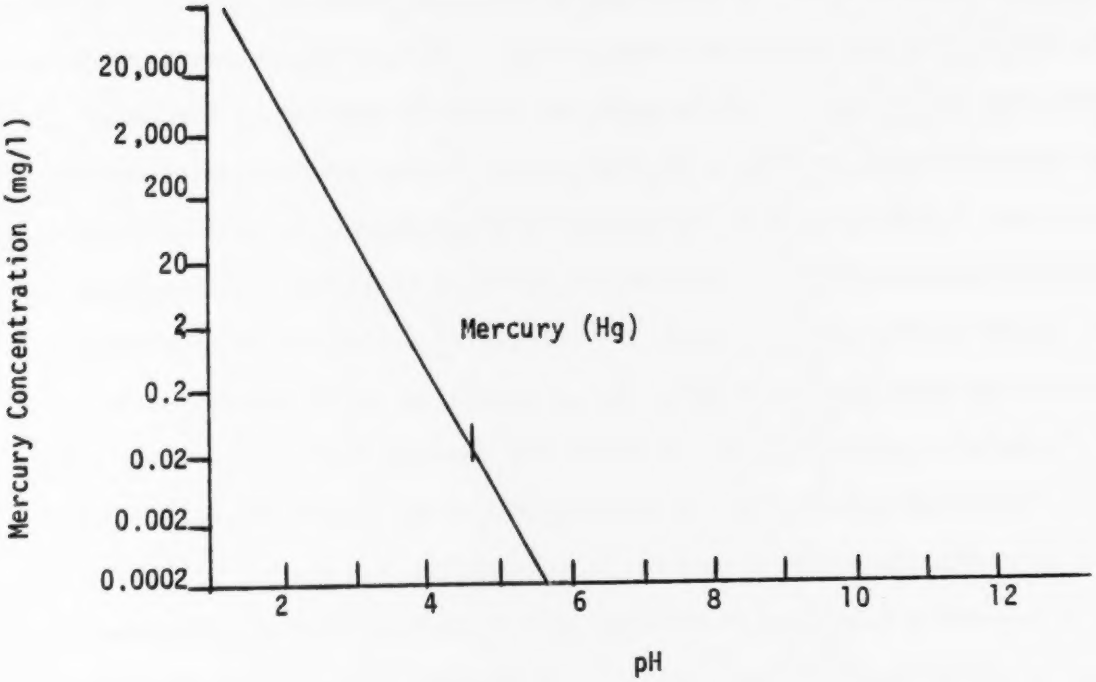


Figure 4-2 Free mercury ion concentrations in equilibrium with solid oxides or hydroxides

For this report, EPA estimated the quantity of metal mining waste that poses an acid drainage problem, using information on the mineral content of metal ores from 115 mines producing more than half of all the tailings generated by the metals mining industry segments represented in the U.S. Bureau of Mines Minerals Availability System data base.

To estimate whether the tailings from these mines have high, uncertain, or no acid formation potential, EPA made the following assumptions:

- If the data base reports that the minerals content of the ore in a particular mine includes pyrites and/or other metal sulfides but does not include carbonates, the tailings from that mine have a high potential for forming acid.
- If the data base reports that the minerals content of the ore in a particular mine includes pyrites and/or other metal sulfides and carbonates, the tailings from that mine have an uncertain potential for forming acid.
- If the data base reports that the minerals content of the ore in a particular mine does not include pyrites and/or other metal sulfides, the tailings from that mine have no potential for forming acid.

The number of mines that generate tailings with high, uncertain, and no acid formation potential are presented, by industry segment, in Table 4-16. According to Table 4-16, mines having the highest acid formation potential are found in the copper, gold, and silver industry segments.

The limitations of these data are:

- The data base does not report the mineral composition of the soil or rock that is removed at mines to gain access to an ore body. It was assumed that ore constituents were similar to waste (gangue)

Table 4-16 Estimated Acid Formation Potential of Tailings at Active Metal Mines by Industry Segment

Mining industry segment	Number of active mines for which minerals data exists	Number of mines with high acid formation potential[a,d]	Number of mines with uncertain acid formation potential[b,d]	Number of mines with no acid formation potential[c,d]
Copper	24	9 (38)	13 (54)	2 (8)
Gold	15	6 (40)	3 (20)	6 (40)
Iron	25	0	9 (36)	16 (64)
Lead	15	1 (7)	14 (93)	0
Silver	19	6 (31)	10 (53)	3 (16)
Zinc	18	0	17 (94)	1 (6)

[a] High Acid Formation Potential - Tailings derived from ores containing pyrites and/or other metal sulfides but no carbonate minerals (which would tend to neutralize produced acids).

[b] Uncertain Acid Formation Potential - Tailings derived from ores containing pyrites and/or other metal sulfides and carbonate minerals. (Such wastes may or may not produce acid, depending on the relative ratio of acid-forming to acid-neutralizing minerals.)

[c] No Acid Formation Potential - Tailings from ores containing no pyrites or other metal sulfides.

[d] Numbers in parentheses are percentage of all mines in an industry segment.

Source: Derived from ore minerals information in U.S. Bureau of Mines Mineral Availability System data base. For this analysis, only mines active in 1982 were considered.

constituents, but it is not clear that this extrapolation could be extended from tailings to overburden. For example, the overburden may be completely different from the ore and have no acid formation potential.

- The reason that EPA categorized the acid formation potential of tailings from mines having both acid-forming minerals (i.e., sulfides) and acid-neutralizing minerals (i.e., carbonates) as uncertain is that the actual acid formation potential of these tailings may range from high to none, depending on the relative concentrations of acid-forming and acid-neutralizing minerals in the tailings. The concentration processes at some mills require the addition of alkaline materials, which are mixed with the tailings and would reduce the acid formation potential of these high-sulfide, low-carbonate ores.
- The presence or absence of water, which is necessary for pyrite oxidation products to form acid, was not considered when categorizing the acid formation potential of these tailings, although many mines are located in arid regions of the country, where the lack of water reduces the potential for acid drainage.
- EPA has not considered whether chemical, mineralogical, biological, climatological, or physical factors might also influence the ability of tailings from particular mines to form acid.

Acid drainage can lower the pH of streams and other surface water. Table C-11 in Appendix C of this report provides a summary of the effects of decreased pH levels on fish.

4.2 ESTIMATED AMOUNTS OF POTENTIALLY HAZARDOUS MINING WASTE

EPA's methodology for estimating the amount of potentially hazardous mining waste is presented in Appendix B to this document. EPA's estimate of annual generation of hazardous waste and of the costs of treating and disposing of hazardous waste are based on projections of the number of mines, the amount of waste generated annually, and the amount of waste existing on site during 1985. EPA felt that a projection to 1985 was preferable to using historical data because of the rapid changes occurring in the mining industry in recent years (i.e., declining production in many segments).

Table 4-17 shows these estimates for eight mining industry segments: asbestos, copper, gold, lead, phosphate, silver, uranium, and zinc. Since there were no data on asbestos mines in EPA's data base, results for asbestos are based on historical data rather than projections; these data probably overestimate the number of active asbestos mines and the amount of waste generated at these mines annually, since EPA is aware that fewer than four asbestos mines are now in operation. EPA did not project results for the iron and molybdenum industry segments, because the wastes generated by these segments do not exhibit any of the hazard characteristics for which EPA tested. In addition, the other metals industry segments are not included in this analysis because of the small number of mines in these industry segments and the small amount of potentially hazardous waste generated at these mines annually.

As shown in Table 4-17, the copper industry segment generates the largest amount of waste annually: 632 million tons per year. The phosphate industry segment, generating 518 million tons of waste per year, has the second highest rate of annual waste generation. In many industry segments, the amount of waste existing on site is very large, exceeding the annual amount of waste generated by a factor of 20 to 40.

Table 4-17 Estimated Number of Active Mines, Annual Amount of Waste Generated, and Waste Existing on Site for 1985

Mining industry segment	Estimated number of active mines	Annual generation of waste (millions of metric tons)	Wastes existing on site (millions of metric tons)[a]
Asbestos[b]	4	5	NA
Copper	22	632	20,789
Gold	100	65	218
Lead	7	9	395
Phosphate	34	518	16,599
Silver	50	17	57
Uranium	50	91	1,564
Zinc	12	3	19

NA indicates data not available.

[a] Data extrapolated to industry segment based on estimates from Charles River Associates.

[b] Asbestos estimates developed by EPA.

Source: Adapted from Charles River Associates 1985c.

Table 4-18 presents EPA's estimates of the amount of mining wastes generated annually that exhibit the RCRA hazardous waste characteristics and mining wastes that may be potential candidates for listing, by industry segment. The estimated amount of corrosive waste generated annually is 50 million metric tons a year. All of this corrosive waste is generated by the copper industry segment. The estimated amount of EP toxic wastes generated annually is 11.2 million metric tons per year, and 63 percent of this EP toxic waste is generated by the gold industry segment. EP toxic waste is also generated by the lead, silver, and zinc industry segments.

Table 4-18 also shows the amount of wastes generated annually of the types that may be potential candidates for listing. The amount of copper dump leach waste (a potential candidate for listing because of low pH and elevated EP toxicity) generated annually is 182 million metric tons. Wastes from gold and silver metal recovery and heap leach operations may be potential candidates for listing because of their high levels of cyanide. The gold and silver industry segments generate 9.3 million metric tons of metal recovery wastes and 14 million metric tons of heap leach wastes annually that may be potential listing candidates. The gold industry generates larger amounts of these wastes annually than the silver industry.

Table 4-19 presents estimated annual generation amounts for wastes with hazardous characteristics that are particularly relevant to mining industry wastes: acid formation potential, radioactivity, and friable asbestos content. EPA estimates that 95 million metric tons of waste have a high potential for forming acid; all of this waste is generated in the copper industry segment. This estimate of waste having high acid formation potential is probably low, because EPA could only estimate the acid formation potential

Table 4-18 Estimated Amount of Waste with RCRA Characteristics Generated Annually and Mining Wastes That May be Potential Candidates for Listing

		RCRA characteristics		Potential candidates for listing		
Mining industry segment	Amount of waste generated annually (million metric tons/year)	Corrosive waste (million metric tons/year)	EP toxic waste (million metric tons/year)	Copper dump leach wastes (million metric tons/year)	Cyanide-treated gold and silver metal recovery wastes (million metric tons/year)	Gold and silver heap leach wastes (million metric tons/year)
Asbestos	5	0	0	0	0	0
Copper	632	50	0	182	0	0
Gold	65	0	7	0	9	11
Lead	9	0	2.9	0	0	0
Phosphate	518	0	0	0	0	0
Silver	17	0	1	0	0.3	3
Uranium	91	0	0	0	0	0
Zinc	3	0	0.3	0	0	0
TOTAL	1,340	50	11.2	182	9.3	14

Source: Derived by EPA from data in Charles River Associates 1985c, PEDCo Environmental, Inc. 1984, and ERCO 1984.

Table 4-19 Estimated Annual Amount of Waste Generated Exhibiting Other Potentially Hazardous Characteristics, By Industry Segment

Mining industry segment	Annual production of waste (million metric tons/year)	High acid formation potential (million metric tons/year)	Radium-226 greater than or equal to 5 pCi/g (million metric tons/year)	Radium-226 greater than or equal to 20 pCi/g (million metric tons/year)	Friable asbestos content greater than 1% by weight (million metric tons/year)
Asbestos	5	0	0	0	5
Copper	632	95	0	0	NA
Gold	65	0	0	0	NA
Lead	9	0	0	0	NA
Phosphate	518	0	352	13	NA
Silver	17	0	0	0	NA
Uranium	91	0	91	80	NA
Zinc	3	0	0	0	NA
TOTAL	1,340	95	443	93	5

NA indicates data not available.

Source: Derived by EPA from data in Charles River Associates 1985c, PEDCo Environmental, Inc. 1984, and ERCO 1984.

of tailings (see Section 4.1.2.4). In addition, EPA classified the acid formation potential of many tailings piles as uncertain because of lack of data on the relative proportion of acid-forming to acid-neutralizing minerals in these tailings, even though some of them probably have a high potential for forming acid.

Table 4-19 presents estimates of radioactive waste at two radioactivity levels--radium-226 equal to or exceeding 5 pCi/g, and radium-226 equal to or exceeding 20 pCi/g. At the 5-pCi/g level, there are 443 million metric tons of radioactive waste generated annually, 352 million metric tons in the phosphate industry segment, and 91 million metric tons in the uranium industry segment. If the 5-pCi/g level is used as the hazard criterion, radioactive waste is the largest single contributor to the total amount of potentially hazardous waste generated by the industry segments of concern. At the 20-pCi/g level, 93 million metric tons of hazardous radioactive waste are generated annually: 13 million metric tons in the phosphate industry segment, and 80 million metric tons in the uranium industry segment.

The total amount of waste generated annually with a friable asbestos content of more than 1 percent by weight is 5 million metric tons per year. This amount may be an underestimate, because EPA did not sample wastes from industry segments other than the asbestos industry for their friable asbestos content.

Table 4-20 shows the estimated amount of potentially hazardous mining waste generated annually, by industry segment. If the radioactivity criterion used is 5 pCi or more of radium-226 per gram, 755.2 million metric tons of potentially hazardous mining waste are generated by these segments annually. If the radioactivity criterion chosen is 20 pCi or more of radium-226 per gram, 405.2 million metric tons of potentially hazardous mining waste are

Table 4-20 Total Amount of Potentially Hazardous Mining Waste Generated Annually

Mining industry segment	Annual production of waste (million metric tons/year)	Total amount of waste with RCRA characteristics (million metric tons/year)[a]	Total amount of potentially hazardous waste[b] (if Ra-226 is greater than or equal to 5 pCi) (million metric tons/year)	Total amount of potentially hazardous waste[b] (if Ra-226 is greater than or equal to 20 pCi) (million metric tons/year)
Asbestos	5	0	5	5
Copper	632	50	276	276
Gold	65	7	24	24
Lead	9	2.9	2.9	2.9
Phosphate	518	0	352	13
Silver	17	1	4	4
Uranium	91	0	91	80
Zinc	3	.3	.3	.3
TOTAL	1,340	61.2	755.2	405.2

[a] RCRA characteristic waste means corrosive or EP toxic waste.

[b] Total potentially hazardous waste means corrosive and EP toxic waste, waste containing cyanide at a level greater than 10 mg/l, radioactive waste, wastes containing friable asbestos content greater than 1 percent by weight, and waste with high acid formation potential.

Source: Derived by EPA from data in Charles River Associates 1985c, PEDCo Environmental Inc. 1984, and ERCO 1984.

generated annually. These total estimates do not equal the sum of the amounts of waste considered hazardous based on individual hazard characteristics, because waste from a single operation may be classified as potentially hazardous for several different reasons. For example, 50 million metric tons of copper dump leach are corrosive; however, this waste is also included in the estimate of 182 million metric tons of copper dump leach waste that may be a potential candidate for listing.

Sixty-one million metric tons of mining industry waste are hazardous, according to the RCRA hazardous waste characteristics of corrosivity and EP toxicity; for comparison, the total amount of hazardous waste generated annually by all nonmining industry segments combined is 64 million metric tons. The portion of mining industry waste that is hazardous because it is EP toxic or corrosive is less than 5 percent of the total amount of waste generated by these industry segments. Of mining industry wastes that may be classified as hazardous because they are EP toxic or corrosive, 82 percent are from copper dump leach operations that generate corrosive wastes, and an additional 11 percent are EP toxic waste generated by the gold industry segment.

Wastes that are hazardous according to the RCRA hazardous waste characteristics of corrosivity and EP toxicity constitute 8 percent of the total amount of potentially hazardous mining waste generated annually, if the radioactivity hazard level chosen for radium-226 is equal to or more than 5 pCi/g. If the radioactivity hazard level for radium-226 is equal to or greater than 20 pCi/g, mining wastes that are hazardous according to the RCRA characteristics of corrosivity and EP toxicity comprise 15 percent of the total amount of potentially hazardous waste generated annually.

4.3 EFFECTIVENESS OF WASTE CONTAINMENT AT MINING WASTE SITES

Because a large amount of mining and beneficiation waste is potentially hazardous, human health and the environment could be adversely affected if these wastes escape containment. EPA commissioned a contractor study[11] to determine whether mining waste management facilities leak and, if they do, whether they release constituents of concern into surface or ground water. The Agency also reviewed the results of other monitoring and mining studies to corroborate its findings.

4.3.1 EPA Study

EPA selected eight mining sites at which to monitor ground and surface water. The study focused on four types of waste (mine waste, tailings, dump leach waste, and mine water) and five mining industry segments (copper, gold, lead, uranium, and phosphate). Seven specific region-commodity categories of waste were monitored: Arizona copper tailings ponds, New Mexico copper dump leach wastes, gold tailings ponds from Nevada and South Dakota, Missouri lead tailings, New Mexico uranium mine water ponds, Idaho phosphate mine waste piles, and Florida phosphate tailings.

Ground water and surface water were monitored at four sites, ground water only at three sites, and surface water alone at one site. At each site, four or five samples were taken over a 6- to 9-month period. Samples were analyzed for selected indicators, properties, or compounds that might be evidence of leakage: antimony, arsenic, barium, beryllium, cadmium, calcium, chloride, chromium, copper, cyanide, fluoride, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, nitrate, phosphate, potassium, selenium, silver, sodium, sulfate, thallium, vanadium, zinc, acidity, alkalinity, conductivity, pH, radionuclides, settleable solids, suspended solids, total dissolved solids, total organic carbon, and turbidity.

Table 4-21 shows the Agency's interpretation of the monitoring results. These results indicate, with a reasonably high degree of confidence, that most of the facilities sampled do leak. However, the data do not demonstrate conclusively that constituents reach concentrations of concern at all sites or that they migrate over long distances.

At the copper mine sites, only ground water was monitored, because southwestern streams, in general, flow only after storms. The site at which copper tailings were monitored has surface runoff diversions for such events. This site also uses thickened discharge, recovers about 50 percent of its pond water, caps filled tailings ponds with alluvium, and then revegetates. Monitoring results showed chloride concentration gradients and an increase in total dissolved solids and sulfate over time in all wells, indicating seepage from the copper tailings pond. Concentrations of sulfate (four to six times higher than natural, local unimpacted levels) and total dissolved solids (two to four times higher than natural but within range for the aquifer) exceeded national drinking water standards in all wells and were even higher for the tailings pond. (Drinking water standards include the National Interim Primary Drinking Water Standards (NIPDWS) and National Secondary Drinking Water Standards. These standards are used as a basis for comparison.) Although the well farthest from the water table mound formed from pond seepage had the best water quality, concentrations of metals were very low (near detection limits) in all wells.

Copper dump leach liquor at the operation studied was very acidic, contained high levels of total dissolved solids, and exceeded nearly all primary and secondary drinking water standards. The pregnant leach liquor is collected in a leachate collection pond and pumped back to the precipitaion

Table 4-21 Results of the Monitoring Program

Industry segment and management practice	Impact on Surface water	Impact on Ground water	Seepage indicators	Comments
Copper tailings pond	NM[a]	yes	Sulfate, TDS, chloride	Low concentration of metals
Copper dump leach	NM	yes	Sulfate, TDS	Seepage is recharging the aquifer
Gold tailings pond	no	yes	Cyanide, chloride, sulfate, nickel, and ammonia	TDS, sulfate, and zinc concentrations in downgradient wells equivalent to concentrations in tailings pond water
Gold tailings pond	yes	yes	Cyanide, chloride, TDS, and pH	Surface water degradation after storms. Cyanide not detected in surface water. Metals did not exceed drinking water standards, although several other indicators did
Lead tailings	no	no	Sulfate, TDS, chloride	Monitoring continues at this site; tailings may be having an effect on shallow ground water
Uranium mine water pond	NM	yes	Sulfate, chloride, TDS, and radionuclides	Barium, a precipitating agent, also found downgradient to pond
Phosphate overburden pile	no	NM		No observable impact
Phosphate sand and clay tailings	no	no	TDS, fluoride, chloride, total phosphorus, and total organic carbon	Seepage greater in shallower aquifer

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[a] NM indicates not monitored.

Source: PEDCo Environmental, Inc. 1984

plant. At this site, ground-water degradation was evidenced by increased concentrations of calcium, sulfate, and total dissolved solids. The leach pile area is in an unlined natural drainage basin, and seepage from it apparently is recharging the aquifer. (Although a hydrogeologic study was not conducted to confirm that the mine pit acts as a ground-water sink, the bottom of the mine pit is 700 feet lower than the water level in the background well.)

Gold tailings ponds receive cyanidation process wastes, have high concentrations of cyanide, arsenic, cadmium, lead, mercury, and selenium, and are typically alkaline. Cyanide was not detected in surface water near either of the gold tailings ponds, although low but detectable cyanide levels in wells at both sites indicate seepage to ground water. At the first site, an underground mine, ore is crushed and then leached with a sodium cyanide solution. Significant downstream increases were found for fluoride, specific conductance, potassium, magnesium, sodium, and sulfate. These increases were thought to be caused largely by natural weathering processes, and the concentrations never exceeded South Dakota cold-water fish propagation stream standards. Alkalinity decreased downstream, and surface water was not considered to be impacted by the tailings pond. The strongest indicators of tailings pond water seepage into ground water are the presence of constituents added during the beneficiation process: chloride and cyanide. Cyanide was detected in three (of six) downgradient monitoring wells; chloride in two. Additionally, sulfate, sodium, nickel, and ammonia concentrations indicated seepage. Cadmium, manganese, iron, sulfate, and total dissolved solids were at or exceeded levels permitted by the drinking water standards. An independent analysis of these data concluded that concentrations of zinc, total dissolved solids, and sulfate in downgradient wells were essentially the same as concentrations in the tailings pond water,[12] supporting the conclusion that contaminants had migrated.

The second mine site in the gold mining industry also employs cyanide leaching. Spent leach liquors and leached ore are disposed of in tailings ponds; decant water is recycled to the mill. In surface water, concentrations of arsenic, manganese, total dissolved solids, and fluoride were significantly higher downstream than upstream, but cyanide was not detected. Tailings pond releases during storms and snowmelt were likely to be responsible for downstream water contamination. Ground-water monitoring revealed concentrations that exceeded drinking water standards for arsenic, manganese, pH, chloride, fluoride, nitrate, lead, manganese, and total dissolved solids. Seepage from abandoned underground mines may have contributed to these elevated levels, particularly for arsenic and manganese. Cyanide was detected at low levels in two of four wells, but metal concentrations did not exceed levels permitted in drinking water standards. The presence of cyanide and the increasing concentrations of total dissolved solids and chloride indicate tailings pond leakage.

The underground lead mine selected for the EPA study is in Missouri, where approximately 80 percent of all lead production occurs. The crushed ore goes through a froth flotation circuit, and tailings are pumped to a pond. This is a zero-discharge facility; a seepage and collection system recycles water to the milling system. Surface water monitoring indicated significant increases in calcium, magnesium, total dissolved solids, sulfate, nitrate, and chloride downstream. These increases were attributed to natural weathering processes, as all levels were within the range reported for streams that do not receive lead mining waste. Although small amounts of cyanide are used to process these ores, cyanide was not detected in surface water. The copper level exceeded the level specified in Missouri standard for the protection of aquatic life both upstream and downstream from the tailings pond. Groundwater monitoring revealed high concentrations of sodium, fluoride, chloride, sulfate, and total dissolved solids; the latter three were considered evidence of seepage. In one sample, total dissolved solids exceeded permissible drinking water standard levels. Groundwater continues to be monitored at this site, which has a set of shallow and deep wells. Preliminary analysis indicates that tailings are having a greater impact on the water quality of the water in the shallower wells.

Only ground water was monitored near uranium mine water ponds in New Mexico. Uranium is recovered from surface and underground mining at this site. Waste management practices include overburden and waste piles, as well as unlined settling ponds. Permissible levels specified in drinking water standards were exceeded in several wells for selenium, nitrate, sulfate, manganese, and total dissolved solids. Elevated concentrations of magnesium, calcium, and sodium reflected the poor quality of the water in the aquifer. High levels of nitrate, magnesium, and total organic carbon may have resulted from leakage from a pond formerly used for sewage disposal. Gross beta and gross alpha concentrations were elevated, and measurable levels of radium-226 were also found. High concentrations of sulfate, chloride, total dissolved solids, and radionuclides in downgradient wells are considered indicators of pond seepage. Elevated downgradient levels of barium are another indication, because barium chloride is added to precipitate radium before water is discharged to the pond.

The impact of phosphate mine waste (overburden) was evaluated at a mine in eastern Idaho. This is an open-pit mining operation in which the overburden is generally backfilled to inactive mine sites. Waste rock is usually graded and revegetated. Surface runoff is collected in basins to remove suspended solids before the water is discharged. EPA concluded, based on monitoring results, that current mining operations have little impact on surface water. Ground water was not monitored, because there were no suitable well sites.

In Florida, surface water and ground water were monitored near phosphate sand and clay tailings. Several waste management practices are used: the clay fractions are slurried to settling ponds and overflow is reused; sand tailings are used as backfill; overburden is piled or used in dike construction. Although levels of fluoride and sulfate were elevated in surface water, quality did not appear to be affected by the tailings. No monitored constituent exceeded its Florida Water Quality Standard. Two ground-water aquifers were monitored: a shallow water table aquifer and a deeper Floridian Aquifer. Elevated levels of several constituents in tailings serve as good indicators of seepage: sodium, sulfate, fluoride, total organic carbon, total phosphorus, radium-226, gross alpha, and gross beta. Of these, sodium, total organic carbon, fluoride, and total phosphorus were statistically higher in one or more wells downgradient to both aquifers than in respective background wells. Although the fluoride level exceeded that of the drinking water standards, all levels were within the range of ambient conditions. Chloride and total dissolved solids, however, were higher than ambient conditions, indicating that sand tailings constituents enter ground water. In conclusion, data indicate that neither clay slime ponds nor sand tailings have seriously affected the quality of shallow ground water. To date, neither practice has had an impact on the deeper Floridian Aquifer, but this aquifer may be recharged by the upper aquifer.

Table 4-22 compares selected concentrations of indicators in ground-water monitoring wells near the mine site with drinking water standards and water quality criteria, where these values are available. Ground-water degradation may be attributable to current and/or past mining practices, although naturally poor background water quality exists in some areas. Further degradation may occur if additional waste constituents (notably metals that have not thus far appeared in high concentrations in the monitoring wells) migrate in the future. Factors governing leaching rates, fate, and transport of constituents are complex, highly site specific, and dependent on physicochemical properties of both the waste and the local subsurface environment. For example, pH, reduction-oxidation potential, adsorption, coprecipitation processes, and complex chemical and hydrologic interactions are unique to each site. Seasonal factors that could not be assessed because of the time constraints of this study are other localized influences on constituent migration and transport. For these reasons, the results of this study cannot be directly extrapolated to industry segments employing similar waste management practices. Other studies may help place this monitoring study in perspective.

4.3.2 Other Studies

This review is not comprehensive, but provides conclusions from earlier EPA studies and studies conducted by state and local governments and the academic community.

Mines can contaminate ground water through waste disposal practices, but the nature of the contamination is highly variable and site specific.[13] Copper waste management practices leak constituents into both surface and ground water. Factors that affect the migration of this leakage include ion

Table 4-22 Concentrations[a] of Seepage Indicators in Ground Water at Selected Monitoring Sites[b]

Constituent	Permissible level in drinking water standards[c]	Water quality criteria for aquatic life[d]	Gold tailings pond	Lead tailings	Uranium mine water ponds	Phosphate tailings
Chloride	250		1.94 - 58.4	22.8 - 44.8	26 - 210	55.3 - 63.2
Cyanide	0.02 - 0.2	0.0035	0.02 - 1.76			
Fluoride	1.4 - 2.4[e]					1.85 - 6.58
Nickel		0.056[f]	0.10 - 0.31			
Radium-226	5 pCi/l				0.25 - 0.33 pCi/l	
Sulfate	250		800 - 1,200	38 - 108	770 - 1,810	
Total dissolved solids	500			269 - 556	1,650 - 5,800	169 - 205

[a] Concentrations are in milligrams per liter except as otherwise indicated.

[b] Values are from one or more wells downgradient or upgradient (or both) from the site.

[c] National Interim Primary Drinking Water Standards (NIPDWS) or Secondary Drinking Water Standards, except for cyanide, where the "detection" limit is given.

[d] Values are for chronic freshwater animal toxicity.

[e] Temperature dependent.

[f] At a hardness of 50 mg/l $CaCO_3$.

Source: PEDCo Environmental, Inc. 1984

exchange capacity, hydraulic conductivity, and carbonate content.[14] Carbonate neutralizes acids, and metals will precipitate when the pH is neutral or alkaline. A study of the Tucson mining district found that leakage from a copper tailings pond, indicated by hardness of and sulfate in the water, degraded ground water downgradient from the pond.[15]

The Globe-Miami area east of Phoenix was also the focus of a study.[16] Copper mine runoff degraded surface water, and leaching practices degraded ground water by lowering the pH and increasing total dissolved solids, sulfate, copper, and other trace metal concentrations. Because of liquids leaching through the soil, alluvia in area washes are contaminated with sulfate, iron, and copper; the plume is advancing downgradient. Abandoned mines have the same potential; but because of the arid climate, significant degradation near these mines has not occurred.

The cyanidation process used in gold mining creates the potential for cyanide migration. Cyanide can be free, part of other compounds, or strongly complexed with metals. An EPA laboratory study[17] showed that some forms are mobile, while others are less so. Movement depends on the type of cyanide and the media through which it travels. Potassium cyanide in leachate is less mobile than water containing cyanide ions in soils. High pH and low clay content increase cyanide mobility. In the soil, cyanide salts are biologically converted to nitrates or become complexed with metals. Without oxygen, cyanides become gaseous nitrogen compounds. These chemical changes take place when cyanide concentrations are low. Former mining practices that did not include wastewater treatment before release can be the source of persistent cyanide concentrations. One company, reopening a mine closed for nearly 40 years, found levels of cyanide far above detection limits (0.14-0.58 mg/l) while drilling test wells before activities began.[18] Before mitigative measures were implemented in 1982, one Nevada gold mine had ground-water levels as high as 5,509 mg/l.[19]

Before proper environmental treatment systems were in place, the Missouri Department of Conservation found a reduction in species diversity in the aquatic habitat in the lead mining district that was directly attributable to mining waste or milling effluent.[20] In another study, surface water in the area had low levels of dissolved metals, indicating potential transport out of the system. A downstream lake was thought to act as a sink, and some sediments had lead and zinc concentrations of 10 mg/l (Missouri Clean Water Commission effluent guidelines are 0.05 and 0.2 mg/l, respectively, for these metals). Releases from the sediments could create concentrations that exceed guideline levels, although little is known about the conditions under which these constituents may be relased from the sediment.[21]

Radionuclide concentrations in uranium mine water are high, but a U.S. Department of the Interior study showed that these concentrations are reduced downstream as a result of adsorption or deposition in the soil.[22] An earlier EPA study of the Grants Mineral Belt (New Mexico) estimated tailings pond seepage at 48.3 million gallons a year.[23]

Idaho phosphate mining has been studied extensively. An earlier study at the EPA site (before current management practices were in place) indicated that mining practices had increased sediment and nutrients, added oils, and reduced the aquatic habitat.[24] Another study concluded that the potential existed for surface and subsurface flow patterns to be altered and for water quality to be degraded by several constituents: arsenic, cadmium, chromium, copper, lead, molybdenum, selenium, vanadium, zinc, uranium, radium-226, nitrogen, and phosphorus. However, the high carbonate content reduces the solubility, and thus the potential impact, of these elements.[25] Finally, a recent USGS survey of the phosphate mining industry indicated that neither sand tailings nor clay slime ponds had a significant effect on ground-water quality.[26]

4.4 STRUCTURAL INSTABILITY OF IMPOUNDMENTS

Impoundments may also pose threats to human health and the environment if they are not structurally stable. The structural failure of impoundments can release large volumes of waste. The causal factors in the failure of unstable waste structures and the subsequent flooding range from cloudbursts or minor earth tremors to extended periods of heavy rainfall, snow, or ice, or the dumping of more wastes than a saturated bank can contain.[27]

Today there are thousands of tailings impoundments across the country that have varying degrees of structural stability. Many of these facilities are located in remote areas, but others are built within flood range of homes and well-traveled roads. If these structures fail, extensive surface water contamination, property damage, and life-threatening situations may occur.

Although dam and impoundment failures in the mining industry segments covered in this report have not yet caused human deaths in the United States, they have been responsible for significant environmental degradation. In Florida, for instance, the collapse of a phosphate tailings dike in 1971 resulted in a massive fish kill and pollution of the Peace River over a distance of about 120 kilometers.[28] Other dam failures at metal mining sites have caused water quality degradation, crop failure, reductions in land values, and fish kills.[29]

Stability problems are becoming more acute as the grade of the ore that is mined decreases (resulting in larger quantities of mine waste and tailings), as dam heights increase, and as the areas near mining facilities become more highly populated.[30] In addition, the recent promulgation of Effluent Limitations Guidelines and Standards for discharges to surface water may have aggravated these stability problems, because mine owners or operators may elect to comply with NPDES permits by impounding larger quantities of water than in the past. The potential danger posed by these impoundments is increased by the fact that many new, large mines are situated in mountainous areas where it is necessary to store large volumes of waste in valleys upstream of inhabited areas.[31]

The Mine Safety and Health Administration's (MSHA's) recent "Report of Progress to Implement Federal Guidelines for Dam Safety" states that "experience has shown that the unregulated disposal of mine and mineral processing waste has the potential for disastrous consequences."[32] According to the U.S. Department of Agriculture, an estimated 10-20 percent of the mine waste disposal embankments in the U.S. and Canada have experienced significant slope stability problems.[33]

Technical personnel from MSHA recently completed field evaluations of 22 metal/nonmetal mine tailings dams located in areas under Bureau of Land Management leases. They determined that no dams were imminent hazards, but they did find technical deficiencies at many of the sites.[34] Investigations of mine tailings impounding structures (tailings dams) in the past 2 years, including five emergency calls requested by metal and nonmetal mine health and safety district managers, have revealed hazardous conditions. Most of the impounding structures inspected show some or most of these serious deficiencies: extremely steep downstream slopes; no emergency outlet structures such as spillways or decant systems; high water, often up to the crest of the dams; cracks and sloughs in the structures themselves; narrow, uneven crests; the absence of trash racks to keep drainage pipes unclogged; and the absence of diverting ditches to keep surface runoff from entering impoundments.[35]

4.5 DAMAGE CASES

EPA has compiled, reviewed, and analyzed data on National Priorities List (Superfund) mine and mill sites, data on damage at other mine and mill sites contained in state files,[36] and information in technical reports documenting cases of mine waste-related environmental contamination.[37,38]

Although this analysis has separated the damage cases into four separate categories (damage at active, inactive, abandoned, and Superfund sites), it is important to note that active sites frequently become inactive, and inactive sites are sometimes abandoned. Therefore, some of the special environmental problems caused by conditions at inactive or abandoned sites (e.g., the erosion of tailings and their discharge into surface water, or the collection and discharge of frequently acidic and mineralized mine water)[39] can only be avoided if active sites undergo some type of closure procedures before they become inactive or are abandoned.

4.5.1 Active Sites

Problems at active mine and mill sites have been documented in Arizona, Colorado, Florida, Missouri, Montana, and New Mexico; these sites represent phosphate, gold, silver, copper, uranium, and molybdenum operations. Releases ranged from catastrophic (loss of pond liner integrity, pond overflow, dam failure,[40] tailings pipeline break) to chronic (pond seepage). Contaminants included cyanides, sulfuric acid, and metals (copper, cadmium, chromium, lead, mercury, and zinc). Both surface water[41] and ground-water[42] quality degradation have been observed, with impairment of aquatic ecosystems most commonly caused by massive releases. Remedial actions included relocating and improving pipelines, replacing liners, installing of leachate recovery systems, and stabilizing dams.

4.5.2 Inactive Sites

EPA has identified inactive mine and mill sites with environmental contamination in Arizona, California, Idaho, Missouri, Montana, and Utah. Mining industry segments represented include gold, silver, copper, mercury, lead, and zinc. Catastrophic releases, often associated with heavy rains, have resulted from dam failures, flood erosion of tailings, or dike washout. Several sites had intermittent or seasonal problems caused by snow melt or spring floods. Other sites, including old mine waste dumps and old tailings impoundments, had chronic seepage or runoff problems. Contaminants measured in surface water at concentrations greater than permissible levels in primary drinking water standards include arsenic, cadmium, and lead. Reductions in populations of fish and other freshwater organisms were observed near at least 12 inactive mine/mill sites that had had catastrophic or chronic releases. Mitigation measures included dam repair, pond lining, development of diversion ditches or secondary ponds, and lime treatment of tailings.[43]

4.5.3 Abandoned Sites

Many of the waste disposal practices that have resulted in major incidents of environmental contamination at abandoned mine sites are no longer used (i.e., the dumping of tailings into streams or onto uncontained piles). EPA identified abandoned sites where environmental contamination resulted from such practices in Arizona, California, Idaho, Montana, and Vermont. Gold (placer and lode), silver, copper, lead, zinc, and unidentified hard rock mining segments were represented. Various combinations of runoff, erosion, and seepage resulted in the release of arsenic, cadmium, cobalt, iron, manganese, lead, and zinc into surface waters, with resultant stress on stream ecosystems over stretches ranging from 2 to 80 kilometers.[44,45] At some sites, diversion ditches and trenches to lower the water table have been used to mitigate these effects, but no mitigation has been attempted at most abandoned sites.

4.5.4 National Priorities List Sites

Environmental contamination problems at the 13 abandoned mine/mill sites on the Superfund National Priorities List (NPL) were generally caused by mine waste disposal practices that are no longer used. These sites are located in Arizona, California, Colorado, Idaho, Kansas, Oklahoma, and South Dakota. Mining industry segments represented are gold/silver (five sites), asbestos (three sites), lead/zinc (two sites), and copper (three sites). The three asbestos sites differ from the other sites in posing an airborne hazard to human health. The other 10 sites have chronic runoff and/or seepage, often with acidic mobilization and transport of arsenic, cadmium, copper, iron, lead, and/or zinc. Ground-water contamination, jeopardized water supplies, or potentially contaminated food chains are the effects common to most of these sites. Degradation of aquatic ecosystems also has been observed at nonasbestos NPL sites. Mitigative measures applied to date include pond sealing, installation of dams, berms, and diversion ditches, and use of the waste in construction. Additional measures will be taken following completion of the remedial plans for each site.

Brief descriptions of environmental contamination problems and threats to human health posed by five NPL sites follow.

1) Mountain View Mobile Home Estates is a 45-unit, 17-acre subdivision near the city of Globe in east-central Arizona. Before 1973, three mills, the Metate Asbestos Corporation, the Jaquays Asbestos Corporation, and the Globe town mill, processed chrysotile asbestos from nearby mines. In 1973 the Metate mill was found to be in violation of EPA air quality standards, and the Gila County Superior Court issued a temporary injunction to cease operations. The injunction was made permanent in May 1974. Before terminating operations, the owner of the Metate Corporation obtained a rezoning of this property into residential subdivisions. Approximately 115,000 cubic meters of asbestos mill tailings were used as the primary fill to level the site, which was then covered with topsoil. The mill buildings, housing, and equipment remained standing on the site. Lots were sold and occupied before the Superior Court injunction was made permanent.

In October, 1979, asbestos contamination of the soil and air was detected at the subdivision. Soil samples contained 5 to 50 percent asbestos fibers, and air samples had as many as 78 fibers/cm^3. The asbestos in the soil and the airborne asbestos had contaminated all the households that were tested.

In December 1979, the Arizona Department of Health Services ordered the responsible asbestos companies to submit site cleanup plans to be implemented during the spring of 1980. In February 1980, the Arizona Division of Emergency Services, with the authorization of the governor, provided temporary housing for the residents (population approximately 130) while their properties were being decontaminated. The Metate mill was demolished, and open ground was capped with 6 inches of soil. The residents returned to their homes, but wind and water erosion exposed some of the asbestos landfill material on the surface of the soil, in the earth around the homes, and in two washes draining the site.

In April 1983, the Centers for Disease Control in Atlanta issued a health advisory for the site, noting continuing health hazards. The Remedial Investigation and Feasibility Study funded by EPA proposed three solutions to the problem.

The site abandonment option was chosen because it was the least costly of the three and eliminated the need for continued site monitoring and selection of an offsite disposal area. In addition to relocating the individuals in this community, it was necessary to demolish existing structures. In this particular case, mining waste contamination made the housing structures unfit for habitation and ruined the community.

2) Acid drainage discharging from numerous mines and dumps at the Iron Mountain site in California flows into Boulder Creek and Slickrock Creek, both tributaries of Spring Creek. Concentrations of cadmium, copper, iron, and zinc in the waters of these creeks exceed their respective permissible levels in Federal drinking water standards by factors of 2 to 5. Spring Creek, with its load of toxic metals, enters into the Sacramento River. The water supply intake for the city of Redding (population approximately 50,000) is 2 miles below the confluence of Spring Creek and the Sacramento River; and the water intake for Bella Vista Water District, which serves apprxoimately 15,000 people, is located 1 mile farther downstream. Water samples taken at the Redding intake show elevated levels of cadmium, copper, iron, and zinc. Samples of fish tissue from resident trout collected in the Sacramento River showed high levels of cadmium, copper, and zinc.

3) At California Gulch, an NPL site in Colorado, approximately 30 private wells have been abandoned because water from these wells is unfit for human consumption. The surface water in California Gulch has been polluted so

extensively by acid mine drainage and the erosion of mining wastes into the stream from the nearby mine site that the stream is devoid of any aquatic life.

4) In 1962, the Celtor Chemical Works in Hoopa County, California, was abandoned by its owners/operators after they received numerous citations for contributing to pollution and fish kills in the Trinity River. Tailings ponds and piles located on the flood plain were the sources of contaminants. In 1964, 2 years after closure of the operation, a flood obliterated the structures and washed the tailings into the stream bed. As late as 1982, soil and sediment samples collected both on site and off site showed elevated and potentially health-threatening levels of cadmium (1.4 to 94.0 ppm), copper (140 to 2700 ppm), lead (6 to 1900 ppm), and arsenic (4.7 to 40 ppm).

5) The Anaconda complex of mining, milling, and smelting facilities in Montana disposed of approximately 5 billion tons of mining wastes in the Silver Bow Creek/Clark Fork River. For a stretch of approximately 180 kilometers, the river system was heavily damaged by tailings materials that were deposited in the river bed and in stream meanders. The river has recently begun to recover, and the beginning of a renewal in aquatic life can be seen in small plants and microinvertebrates that have become reestablished there. Although the waste disposal practices of the early to mid-1900s that caused this destruction are now prohibited by state and Federal laws; e.g., the Clean Water Act, the results of the waste practices of 40 years ago may take another 40 years, and a considerable amount of resources, to undo.

4.6 RISK ANALYSIS

As shown in the previous portions of this section, some wastes from mining and beneficiation do have the potential for being hazardous to human health and the environment. EPA's waste sampling and analysis indicate that some mine waste and mill tailings are EP toxic, generally for lead. The sampling and analysis also showed that some leachates from copper leach dump operations have the characteristic of corrosivity, with a pH less than 2.0; and even those that are slightly less acidic can seriously jeopardize the quality of ground water. Other waste streams, although not hazardous under current RCRA characteristics, contain potentially hazardous concentrations of asbestos, cyanide, or radioactive isotopes. Some tailings have the potential for acid formation, and tailings impoundments may be subject to catastrophic breaks. Ground-water monitoring studies by EPA and other organizations have demonstrated that seepage from tailings impoundments into ground water is common. Finally, various degrees of damage have been caused by chronic or sudden releases from active, inactive, or abandoned mine and mill sites.

The previous portions of this section do not, however, provide quantitative estimates of releases, exposures, or risks associated with various mine and mill waste disposal practices. Without this information, the efficacy of current and alternative management practices cannot be compared. Therefore, EPA is now studying the use and release of cyanides and acids at typical mining and beneficiation operations. Specifically, cyanide releases from metal recovery circuits and heap leaching operations are being examined. Sulfuric acid releases being examined include those from active, inactive, and abandoned copper leach dumps and copper mill tailings impoundments.

EPA also has begun general studies relating the respective locations of drinking water supply systems and human population centers to mines and mills. A preliminary analysis, based on the Federal Reporting Data System, indicates that for 58 mine/mill sites, 20 have public ground-water systems within 5 kilometers of the site. These public water systems serve populations ranging from 42 to 47,494. Another EPA data base, the Graphic Exposure

Modeling System, uses Census Department data for population distributions and shows that people live within 5 kilometers of the mines at 30 of the 58 sites, with total populations between 5 and 11,736. Only 11 of the 58 sites have both resident populations and public ground-water systems within 5 kilometers.

If EPA identifies significant mining waste releases of cyanides, acids, or other constituents of concern, further analyses will focus on actual or potential risks to human populations or aquatic ecosystems. These studies will take into consideration the properties of various kinds of mine overburden, mill tailings, and heap/dump materials. Constituents other than EP toxic metals will be examined to determine whether their release can jeopardize aquatic organisms. Degradation, attenuation, precipitation, and other processes affecting the transport of released materials will be examined. To assess the potential for ground-water contamination, site-specific estimates will be made for such factors as porosity, permeability, and moisture content in the unsaturated zone, and for hydraulic conductivity in the saturated zone.

The risk analyses will be used to quantify threats that releases from mine and mill wastes pose to human health and the environment. These analyses will permit EPA to consider the wide variation in mining practices and settings, and to determine how changes in management practices can be implemented to improve and protect human health and the environment. EPA would conduct risk analysis as part of the development process for any major regulation of hazardous waste from the mining and beneficiation of ores and minerals.

4.7 SUMMARY

To identify mining and beneficiation wastes with the potential to endanger human health and the environment, EPA conducted an extensive program of sampling and analyzing mine waste, mill tailings, and wastes from heap and dump leach operations to determine their chemical properties. These studies were supplemented by data from ground-water monitoring, estimates of acid formation potential, a survey of state files to obtain documented cases of damage to human health and environment, and a review of the pertinent literature. In the sampling and analysis studies, corrosivity and EP toxicity were measured, because they are the RCRA Subtitle C characteristics most likely to be exhibited by wastes from mines, mills, and leach operations. The radioactive content of many solid and liquid samples also was measured. When appropriate, measurements were taken of asbestos or cyanide content. Most mine waste samples, most settled solid samples, and some low-grade ore samples were also subjected to a modified EP toxicity test, in which deionized water, rather than acetic acid, was used as the extracting medium. It should be noted that EPA has not yet performed quantitative assessments of the risks posed by mining wastes. These will require measurement or estimation of waste constituent transport, as well as receptor population exposure, dose, and response.

Extrapolating from the sampling and other analytic results, EPA estimated the amounts of potentially hazardous waste generated by the mining industry segments of concern annually. Estimated amounts are: 50 million metric tons a year (MMTY) of corrosive wastes; 11 MMTY of EP toxic wastes; 23 MMTY of cyanide-containing wastes; 95 MMTY of wastes with high acid formation potential; and 182 MMTY of copper leach dump wastes with the potential for releasing toxic metals and acidic (but not corrosive) liquids. If a

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radioactivity level of 5 pCi per gram of waste is chosen as the radioactivity hazard criterion, 352 MMTY of phosphate mine waste and mill tailings and 91 MMTY of uranium overburden and low-grade ore would be considered hazardous. The total amount of potentially hazardous waste generated annually, 755 MMT, is not equal to the sum of the wastes in these categories because some of the wastes are in more than one category.

Analyses of ground water monitoring results and damage cases showed that a number of constituents leak from tailings impoundments and copper leach dump operations. However, it is not clear that this seepage constitutes a danger to human health, although it could degrade the quality of water in aquifers. The instability of impoundment dams was identified as a possible threat to human health and the environment, with damage at active, inactive, and abandoned sites attributed to catastrophic releases of impounded slimes, sands, and water.

In assessing the 13 mine/mill sites on the National Priorities List (NPL), prepared under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), EPA determined that the contamination problems associated with these sites were generally caused by disposal practices no longer used. Natural recovery and decontamination processes at these sites have been slow, and additional time and resources will be needed before recovery is complete.

To determine the degree of risk from wastes at existing mine, mill, and leaching operations, identified as hazardous or potentially hazardous, EPA is conducting studies on release rates, exposure pathways, and possible effects on human health and the environment. These risk assessments will permit EPA to consider the wide variability in mining wastes and environments and to determine which changes in management practices would be most beneficial.

SECTION 4 FOOTNOTES

[1] PEDCo Environmental, Inc. 1984.

[2] ERCO 1984.

[3] Harty and Terlecky 1982.

[4] Liquid wastes are also considered corrosive and therefore hazardous if they corrode steel at a rate greater than 6.35 mm per year at a test temperature of 55°C, as determined by the test method specified in National Association of Corrosion Engineers Standard TM-01-69, standardized in "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods" or an equivalent test method approved by the Administrator (40 CFR 261.22). "EPA chose metal corrosion rate as its other barometer of corrosivity because wastes capable of corroding metal can escape from the containers in which they are segregated and liberate other wastes" (45 FR 33109, May 19, 1980). Because of the preliminary nature of the findings of this report, and because mining wastes are not likely to be stored in metal containers, EPA's corrosivity analyses for this report are based solely on the pH measure.

[5] Wastes are also considered EP toxic (and thus hazardous) if the extract of a representative sample of waste contains any of the following pesticides or herbicides at levels specified in 40 CFR 261.24 (b), Table 1: Endrin; Lindane; Methoxychlor; Toxaphene; 2,4-D; 2,4,5-TP Silvex. EPA did not use the EP toxicity test to analyze mining wastes for these contaminants.

[6] US EPA 1982a.

[7] US EPA 1982a.

[8] US EPA 1982b.

[9] Cook et al. 1976.

[10] US EPA 1982a.

[11] PEDCo Environmental, Inc. 1984.

[12] Williams and Steinhorst 1984.

[13] US EPA 1977.

[14] PEDCo Environmental, Inc. 1984.

[15] Pima Association of Governments 1983.

[16] Gordon 1984.

[17] US EPA 1976.

[18] Letter to Nevada Division of Environmental Protection from Margaret Hills, Inc. 1981.

[19] File memo from Cortez Gold Mines, Cortez, NV, 1983.

[20] Ryck and Whitely 1974.

[21] Jennett and Foil 1979.

[22] U.S. Department of the Interior 1980.

[23] US EPA 1977.

[24] Platts and Hopson 1970.

[25] Ralston et al. 1977.

[26] U.S. Geological Survey, U.S. Bureau of Land Management, and U.S. Forest Service, 1977.

[27] Carroll 1983.

[28] BOM 1981a.

[29] SCS Engineers 1985.

[30] Soderberg and Busch 1977.

[31] Klohn 1981.

[32] MSHA 1983.

[33] USDA Forest Service 1979a.

[34] MSHA 1983.

[35] MSHA 1983.

[36] The data from the state files and the National Priorities List were not analyzed in depth, nor were any of the sites visited, but enough documented cases were obtained to demonstrate the range and severity of contamination problems that may be associated with mine and mill waste disposal.

[37] SCS Engineers 1985.

[38] Unites et al. 1985.

[39] Martin and Mills 1976.

[40] Schlick and Wahler 1976.

[41] Missouri Geological Survey 1979.

[42] Gordon 1984.

[43] SCS Engineers 1984.

[44] Schrader and Furbish 1978.

[45] Jennett and Foil 1979.

SECTION 5

THE ECONOMIC COST OF POTENTIAL HAZARDOUS WASTE MANAGEMENT

This section examines the potential cost to facilities and selected segments of the mining industry if EPA were to regulate mining and beneficiation wastes under the hazardous waste controls of Subtitle C of RCRA. The cost study on which these estimates are based was restricted to five major metal mining segments (copper, lead, zinc, silver, and gold), and covered mines currently active in 1984.[1] The estimates do not cover mining segments in which there are potential hazards from radioactivity or asbestos, although studies assessing the cost of reducing exposure to radioactivity are underway.

To examine potential costs that might be imposed on the selected metal mining segments, the Agency constructed eight hypothetical regulatory scenarios differing in degree of impact. These scenarios utilized combinations of four different sets of management standards, varying in stringency, and two different sets of hazardous waste criteria for determining which waste streams would be regulated. The estimated incremental costs reflect the added expenditures that facilities and industry segments would incur above and beyond the cost of current waste management practices.

The results are tentative, since they are based on only a sampling of sites, very general engineering cost evaluations, and various hypothetical regulatory scenarios. Nevertheless, the estimates do provide a first approximation of the potential level and variation of cost under the specified assumptions. They do not evaluate broader economic effects such as implied mine or mill closings, employment losses, price changes, or international trade effects.

The subsections below describe the methods and summarize the results.

5.1 COST METHODOLOGY

To estimate the costs of potential regulation, EPA (1) established criteria for determining whether waste is potentially hazardous; (2) developed hypothetical alternative regulatory standards for waste management practices with different degrees of stringency; (3) estimated the incremental cost of imposing those standards at a large sample of mining facilities; and (4) extrapolated these results to the universe of applicable mining facilities in the segments covered by the study.

The cost study focused only on currently active (1984) "major" mines--i.e., mines generating greater than 10,000 short tons of ore per year, except for gold and silver operations where a lower production cutoff was used. For the five metal segments studied (copper, lead, zinc, gold, and silver), the study results cover approximately 190 active mine sites representing an estimated 95 percent of the total active mines and 99 percent of the total amount of waste currently generated in these five segments.

EPA established two levels of criteria, referred to here as Scenarios A and B, for determining whether waste is hazardous. EPA also defined four levels of regulation, varying from imposing full Subtitle C regulations (most stringent) to imposing only a basic maintenance and monitoring function (least stringent). Combining the two hazardous waste scenarios and the four regulatory standards resulted in eight different scenarios.

To estimate the additional cost of each of these eight scenarios at specific sites, EPA (1) identified the capital and operation and maintenance needs for each scenario; (2) developed engineering cost functions reflecting these requirements; (3) established a data base with all the necessary information (e.g., waste volumes, acreage, perimeter distance, current waste management practice) for estimating costs from the cost functions; and (4) applied information from 47 specific mines to the cost functions to develop the incremental costs at those sites.

Finally, EPA extrapolated the site-specific results to the universe of mining waste to develop industry totals. It did so by projecting from the site-specific cost by industry segment (copper, gold, silver, lead, zinc), by waste operation (mine waste, leach operation, tailings), and by scenario. The distinguishing feature of this approach is that the costs reflect real-world, site-specific data.

5.1.1 Hazardous Waste Criteria

Regulated waste volumes depend on the criteria selected for determining whether wastes should be regulated, and EPA used the basic waste characteristics described in Section 4 to specify which waste streams should be considered as potentially hazardous for costing purposes, creating two sets of waste: "A" and "B." (Estimates of the volume of potentially hazardous wastes are discussed in Section 4.2.)

"A-Scenario" Wastes include waste streams meeting the Subtitle C tests for EP toxicity and corrosivity. In addition, they include gold mine tailings wastes from cyanide-process metal recovery operations (originally promulgated as interim final Subtitle C listed hazardous wastes prior to the Section 3001 exemption).

"B-Scenario" Wastes include all wastes under the "A" list, as well as:

- Gold and silver heap leach operations (because of cyanide content);

- Wastes with high acid formation potential--i.e., those found to contain high sulfides (mainly pyrites) and low carbonate or other buffering mineral content (as defined in Section 4); and
- Copper dump leach liquids (because of acidity).

The "B" list of wastes represents a range of mine waste characteristics of concern over and above the hazard characteristics already contained in existing EPA hazardous waste regulations as expressed by the "A" list. The Agency examined the "B Scenario" list to be able to explore, quantitatively and systematically, the waste quantity and management cost implications of regulating these additional wastes of concern.

5.1.2 Regulatory Standards

EPA structured four regulatory alternatives for different levels of waste management practice. The regulatory alternatives covered a range of variations on Subtitle C management standards, ranging from the full set of standards at one extreme to a much more modest program of basic preventive maintenance and ground-water monitoring at the other end of the spectrum.

The Full Subtitle C Regulatory Scenario (Scenario 1) provides for a full application of current EPA hazardous waste regulation to potentially hazardous "A" or "B" mine waste, leach piles, and mill tailings. For present costing purposes, it represents a maximum cost strategy, including: a security fence around the perimeter, capping of both existing and new waste sites at closure, corrective action via interceptor wells for existing waste amounts (assuming 10 percent of the sites need them), and liners for all new waste piles, leaching areas, and tailings ponds. It also requires activities common to all of the alternative management strategies:

- Permitting;
- Surface water run-on and runoff diversion/collection ditches (mine waste only);

- Ground-water monitoring wells and testing;
- Leachate collection ditches; and
- Post-closure inspection, drainage maintenance, and ground-water monitoring.

The Tailored Standard Scenario (Scenario 2) represents an intermediate cost alternative. This scenario includes the five common activities listed above. However, the waste management technique here is distinguished by substitution of waste treatment processes where considered feasible--namely, the removal of cyanide from gold and silver tailings and removal of sulfides (pyrites) from copper mill tailings. The scenario assumes that all sites would require interceptor wells because it assumes a 100 percent failure rate for all waste sites, except for treated wastes at gold and copper sites (treatment is the alternative to interceptor wells).

The Corrective Action Scenario (Scenario 3) also represents an intermediate alternative with to regulatory standards that are less stringent than those embodied in Scenario 1. The applicable activities are identical to those listed under Scenario 2 (including the 100 percent failure assumption), with the exception that cyanide is not removed from gold and silver tailings, and sulfides are not removed from copper mill tailings.

The Basic Maintenance and Monitoring Scenario (Scenario 4) includes only the five activities common to the other scenarios. By design, this represents a least-cost scenario consistent with providing a measure of protection against surface water contamination and a first warning of any offsite movement of contaminated leachate. It can also be regarded as the first stage of a corrective action strategy.

Combining the four regulatory standard alternatives with the two alternative sets of potential hazard criteria yields eight possible levels of cost. Table 5-1 summarizes the definitions of costing scenarios in terms of their alphanumeric designations: the numbers 1 through 4 represent the alternative regulatory standards, and the letters A and B represent the applicable potential hazard criteria.

5.1.3 Estimating Incremental Costs at Specific Sites

EPA identified the cost elements required for each scenario. Cost elements are the individual capital requirements, and individual operation and maintenance requirements. EPA also developed engineering cost functions for each cost element for performing the activities that the management standards require. EPA then created a data base for 47 mining facilities that incorporated the information necessary to calculate costs from the engineering cost functions. This included identifying the current waste management practice (baseline practice) at each of the 47 sites. This information was necessary to develop incremental costs that reflect the costs of practices required under each of the four regulatory standards above and beyond the baseline practice. In addition, the data base incorporated information relative to site-specific geography, product production, total waste quantities, waste quantities that would meet the hazardous waste criteria, type of industry, and type of waste operations. Finally, EPA computed the incremental cost for each scenario at each site by applying the data base information to the engineering cost functions.

5.1.3.1 Cost Elements

As discussed previously, imposing various degrees of regulation requires a different mix of outlays for capital, operation, and maintenance. The mix of cost elements varies by the stringency of the regulatory standard. For convenience, Table 5-2 summarizes the cost elements included in each of the four regulatory standard scenarios. A discussion of each element follows.

Table 5-1 Definition of Costing Scenario

Variations by specified hazards	Variations by type of regulatory approach
	1. Full Subtitle C Regulations
"A" SCENARIOS: Subtitle C Definitions:	2. Tailored Standards (varying by type of hazard)
• EP Toxicity Characteristic • Corrosivity Characteristic • Cyanide Gold-Mine Tailing Liquid Waste	3. Corrective Action 100% failure bracket
"B" SCENARIOS: Subtitle C Above, Plus:	
• Cyanide Toxicity Characteristic • High Acid Generation Potential Characteristic • Copper Dump Leach Listing	4. Basic Maintenance and Monitoring Zero failure bracket

Table 5-2 Summary of Cost Elements Included for Each Scenario

Cost element	Regulatory scenario 1	2	3	4
1. Permitting	X	X	X	X
2. Leachate system	X	X	X	X
3. Monitoring system	X	X	X	X
4. Run-on/runoff system	X	X	X	X
5. Post-closure maintenance and operation	X	X	X	X
6. Site security	X			
7. Liners (new waste only)	X			
8. Closure cap	X			
9. Tailings treatment (for copper and gold)		X		
10. Corrective action via interceptor wells	X[a]	X[b]	X	

Note: Explanations as to variations between and within scenarios are contained in the text.

[a] Only for existing accumulated waste sites (that were closed at time of RCRA implementation).

[b] Exceptions: gold and copper tailings (subject to treatment instead).

Permitting. Mining operations with hazardous wastes would require RCRA permits. Permits would be based on geological and engineering studies describing the plan for managing wastes and containing or treating contamination. Incremental costs in this study vary among states with more advanced permitting requirements and those with less.

Site Security. RCRA regulations require that security be provided to prevent the general public and livestock from coming into contact with hazardous waste. For this study, EPA assumed that operators of facilities would install and maintain cyclone fences around all hazardous waste areas during their active lifetime and a 30-year post-closure period.

Caps and Liners. RCRA Subtitle C rules require caps when disposal sites are closed and that new waste landfills and impoundments be lined. The cap assumed for this study consists of vegetation, topsoil, clay or sand, polyethylene cover, and clay. We assumed that liners were composed of a combination of clay and synthetic liner materials.

Monitoring Wells. RCRA rules require ground-water monitoring of hazardous waste disposal sites. The study assumes that wells will be located around the general perimeter of each waste disposal operation (500 feet between each well), and that four replicate samples will be taken and analyzed twice a year for appropriate contaminants.

Run-On and Runoff Systems. Regulations provide that precipitation be directed around hazardous waste piles to avoid leaching of contaminants. Runoff from surfaces of piles must also be controlled. The costs here reflect primarily ditching and flow control systems.

Leachate Collection Systems. RCRA rules require a system to collect and treat contaminated seepage from hazardous waste piles. A full system includes: (1) ditches or trenches on the downgradient sides of the waste pile;

(2) an intermediate liquid storage system; and (3) a chemical treatment plant.

Corrective Action via Interceptor Wells. At some sites, contamination migrates into ground water, forming a plume that can migrate from the site. When this happens, RCRA Subtitle C rules require corrective action. For this study, EPA assumed that interceptor wells would be installed in the plume, or at the downgradient edge of the plume, to pump the contaminated water to the surface. EPA assumed that all contaminated water would be sent to a treatment plant. In Scenario A, interceptor wells are installed at closure only for existing waste.

Tailings Treatment. This applies only to Scenario 2 where treatment of new waste is employed when feasible rather than interceptor wells. Specifically, EPA assumes that future gold and copper ore tailings would be treated to separate out pyrite concentrates for disposal as a hazardous waste, using a flotation circuit, and that a treatment plant would be installed to destroy cyanide in gold beneficiation operations.

Closure. When the useful life of a waste pile or tailings pond is over, the study assumed the site would be capped with impervious cover material. The design and cost of the cap depends on whether the waste site is from past operations or future operations.

Post-Closure. Operation and maintenance (O&M) costs are assumed to be incurred for 30 years after closure. The annual O&M costs would consist of several elements: (1) maintenance of the cap and fencing; (2) inspection; (3) detection or compliance monitoring; (4) maintenance of the run-on and runoff systems; (5) operation of the leachate collection; and (6) operation of the interceptor well/treatment system.

Financial Assurance. RCRA Subtitle C rules require firms to demonstrate that they can meet closure and post-closure costs. They may do so by posting surety bonds, by purchasing a letter of credit, by establishing a trust fund, by purchasing an insurance policy, or by passing a financial test.

5.1.3.2 Cost Functions

Engineering cost functions were developed for each of the waste management practice cost elements listed in Table 5-2. The functions generally take the form: $C = aV^b$, where C = cost, a = a constant, V = the volume of waste, and b = the elasticity of cost with respect to volume (which shows how cost changes as a result of small volume changes). Many of the functions use the number of acres or perimeter distance as the independent variable rather than waste volume. Permitting costs are based on type and size of mine, as well as current State agency permitting requirements.

5.1.3.3 Sample Facility Data Sources

The Agency's cost study utilized and built upon a mine facility data base providing site-specific data for 47 metal mining properties, with information on geophysical characteristics, mine/mill technologies and efficiencies, historical production levels, and other salient factors.[2] Additional site-specific data were assembled on the type and size of current waste management areas and practices, as well as life expectancy of ore bodies and current production cost factors. The data were supplemented by survey information on current State mining waste regulations. These data provide the primary inputs for estimating historical and current mine, tailings, and leach pile waste generation rates as well as simulating baseline management practices at each of the 47 properties.

EPA waste characteristics sampling data were available for one or more waste streams at 41 of the 47 facilities; and the combination of these two data sources then formed the basis for calculating potentially hazardous waste quantities and incremental hazardous waste management compliance costs for each database facility under the various hypothetical regulatory scenarios, using the cost functions previously described.

Appendix B provides a fuller discussion of the facilities data base, the methods used in estimating waste generation rates, and the techniques employed to extrapolate waste quantities and compliance costs from the sample sites to the segment totals for the mining segments in the study.

5.1.4 Total Number of Facilities and Waste Quantities Regulated

EPA aggregated the site-specific regulated waste quantities, capital costs, and O&M costs for each facility in the data base by industry, by scenario, and by waste operation. The resulting industry totals for numbers of facilities affected and regulated waste quantities are summarized for the specific segments in Table 5-3.

As indicated in Table 5-3, 99 out of 191 metal mining facilities (52 percent) and 67 million metric tons out of a total annual generation of 725 million metric tons (9 percent) of metal mining waste would be subject to potential Subtitle C regulation under Scenario A. However, except for gold, less than half of the facilities in any given segment would be affected. Furthermore, not all of a given affected facility's waste sources would necessarily be subject to regulation. For example, copper mine and tailings wastes were not found by our sampling to be potentially hazardous under our Scenario A definition, but some copper dump leach piles are potentially hazardous in Scenario A. This accounts in part for the relatively low percentage of waste meeting the hazard criteria, in contrast to the higher percentage of facilities. In addition, the (listed) cyanide process tends to dominate the gold milling/processing operation, but a relatively smaller fraction of total waste.

Table 5-3 Numbers of Potential RCRA Mine Facilities and Quantities of Hazardous Waste in EPA Cost Study, Scenario A and B, by Mining Sector

	Number of facilities		Annual waste generation (millions of metric tons/year)	
	Regulated/ total	Percent regulated	Regulated/ total	Percent regulated
	Scenario A			
Copper	6/22	27	50/632	7.9
Gold	75/100	75	13/65	19.6
Silver	12/50	24	1/17	5.7
Lead	3/7	43	3/9	33.3
Zinc	3/12	25	0.3/2.4	11.5
Totals	99/191	52	67/725	9.3
	Scenario B			
Copper	21/22	96	276/632	43.7
Gold	100/100	100	24/65	36.6
Silver	25/50	50	4/17	22.3
Lead	3/7	43	3/9	33.3
Zinc	3/12	25	0.3/2.4	11.5
Totals	152/191	80	307/725	42.3

Source: Estimated by Charles River Associates 1985a.

In Scenario B, the fraction of firms under regulation increases to about 80 percent overall, and the fraction of regulated waste increases to about 40 percent. Almost all copper sites (although still less than half of the total waste volume) would face regulation under this scenario, as well as all gold mines (due to cyanide heap leach and metal recovery). For silver, lead, and zinc, the fraction of facilities affected ranges from 25 to 50 percent and the fractions of waste regulated from 11 to 33 percent under Scenario B..

This methodology relies on the use of real-world sites with site-specific information concerning prevailing regulations and current waste management practices, geography, and mine operations. It requires a high level of detail in building up the cost estimates for each EPA data base site. The results presented below are based on the application of this methodology to a large sample (47) of real-world sites and the extension of those results to the remaining sites.

5.2 POTENTIAL COSTS OF RCRA SUBTITLE C WASTE MANAGEMENT

This section discusses potential costs for the metal mining industry in the aggregate, for individual segments, and for individual mine facilities if certain wastes were managed as hazardous wastes under various regulatory scenarios. The discussion also provides some insights as to the relationship of compliance costs to mine production costs.

5.2.1 Potential Total Cost for the Metal Mining Industry

EPA's cost analysis leads to three principal findings with respect to total potential cost. The first is that the waste management costs of RCRA could be quite substantial under the types of regulatory scenarios that this report considers, as Table 5-4 illustrates. In annualized cost terms, costs for the five metal mining segments would be measurable in the millions of

Table 5-4 Potential Total Cost For Metal Mining Industry[a] Under Various RCRA Regulatory Scenarios

Regulatory scenarios[b]	Lifetime[c] ($ millions)	DPVL[d] ($ millions)	Annual[e] ($ million)
1A	$2,421	$1,279	$185
2A	937	305	47
3A	1,036	332	46
4A	128	60	7
1B	9,985	5,746	854
2B	3,577	1,139	210
3B	2,809	800	118
4B	330	137	17

[a] Industry segments include: copper, lead, zinc, gold, and silver.

[b] See Subsection 5.1.1 and Table 5-1.

[c] Lifetime cost (1985 dollars), not discounted, including: closure and 30 years post-closure costs for existing wastes; opening and managing a new waste management facility for 15-year future operations; closure at end of 15th year; post-closure management for 30 years.

[d] Discounted Present Value of Lifetime Costs, as listed in note (c). Real discount rate of 9.0 percent.

[e] Lifetime Costs Annualized over 15-year future mine production period using a real discount rate of 9.0 percent.

Source: Estimated by Charles River Associates 1985a.

dollars per year up to several hundred million dollars per year over a 15-year mine production cycle. Lifetime costs (undiscounted) for operating the mines in five metals segments would be measurable in the hundreds of million dollars, possibly up to several billion dollars over the next 15 years of mine production.

The second major conclusion is that costs vary substantially among the RCRA management scenarios chosen for analysis. Generally speaking, the highest cost scenarios (1A and 1B) are several times more costly than the intermediate cost counterparts (2A and 3A, 2B and 3B). Similarly, the minimum maintenance and monitoring scenarios (4A and 4B) cost only a fraction as much as the intermediate cases.

The third finding is that the additional waste management cost incurred by adding additional B-Scenario wastes is also very substantial: Scenario B is typically two to four times more costly than Scenario A for given regulatory standards or strategies.

The figures presented in Table 5-4 assume that the potentially hazardous portions of both existing waste (accumulated at these sites from past operations) as well as new (future) waste generated at these sites would be managed as RCRA Subtitle C hazardous waste. If only new wastes generated in the future were to be regulated, the costs would be 40 to 70 percent of those shown in Table 5-4, depending on the scenario considered.

5.2.2 Potential Costs for Individual Segments

Potential total costs for the five individual metal mining segments vary widely among the segments analyzed and across alternative regulatory scenarios, as Table 5-5 illustrates. By far, the largest aggregate lifetime cost for each alternative falls on copper mining, because of the extremely large quantities of waste and the relatively high proportion of total waste

Table 5-5 Potential Total Costs For Selected Metal Mining Sectors Under Various RCRA Regulatory Scenarios

	Subtitle C		Tailored standards	
Sector	1A	1B	2A	2B
	Lifetime costs ($ million)[a]			
Copper	$1,400	$8,300	$400	$2,400
Gold	670	1,200	250	770
Silver	46	180	60	180
Lead	260	260	180	180
Zinc	45	45	47	47
Totals	$2,421	$9,985	$937	$3,577
	Discounted present value ($ million)[b]			
Copper	$ 710	$5,000	$ 96	$ 770
Gold	370	490	110	230
Silver	28	90	23	63
Lead	140	140	58	58
Zinc	26	26	18	18
Totals	$1,279	$5,746	$305	$1,139
	Annualized costs ($ million/year)[c]			
Copper	$ 110	$ 740	$ 14	$ 150
Gold	48	75	17	37
Silver	4	16	4	11
Lead	19	19	9	9
Zinc	4	4	3	3
Totals	$ 185	$ 854	$ 47	$ 210

[a] Lifetime cost (1985 dollars), not discounted, including: closure and 30 years post-closure costs for existing wastes; opening and managing a new waste management facility for 15-year future operations; closure at end of 15th year; post-closure management for 30 years.

[b] Discounted Present Value of Lifetime Costs, as listed in note (a). Real discount rate of 9.0%.

[c] Lifetime costs annualized over 15-year future mine production period, using a real discount rate of 9.0%.

Source: Estimated by Charles River Associates 1985a.

that is of potential concern, particularly in the dump leaching and milling operations. The gold segment bears the second highest lifetime total cost since most gold production uses cyanide processes either in leaching or milling operations.

5.2.3 Potential Costs for Individual Mine Facilities

As noted previously, the number of mine facilities that might be subjected to hazardous waste regulations is highly uncertain, depending on various possible definitions of hazardous waste constituents, variations in natural mineral deposits, and differences in ore processing methods. EPA waste sampling suggests wide variations among different segments as to percentage of mines with potentially hazardous waste, as well as wide variations within individual segments regarding possible quantities and characteristics of such waste materials. This section examines potential cost implications for individual facilities among and within the five segments analyzed.

Table 5-6 provides a comparative summary of individual mine facility cost estimates for two illustrative scenarios--Scenario 1B (the highest cost scenario estimated) and Scenario 4B (the lowest cost scenario for the B-waste group). Potential costs are presented on both a lifetime and an annualized basis. For the high-cost scenario (1B), average lifetime costs for affected facilities would range from $7 million for silver mines up to almost $400 million for individual copper mines. Annualized and discounted over a 15-year mine production cycle, these would translate into new annual average cost burdens for individual mines, ranging from $600,000 per year (silver mines) up to $35 million per year (copper mines) per facility.

The facilities with the highest costs--those with the greatest volumes of potentially hazardous wastes or especially difficult management conditions--would experience additional management costs that would be significantly

Table 5-6 Potential Incremental Compliance Costs For Individual RCRA Mine Facilities For High- and Low-Cost Scenarios

	Scenario 1B		Scenario 4B	
	Average facility	Maximum cost facility[a]	Average facility	Maximum cost facility[a]
	------------- Lifetime costs ($ millions)[b] ----------------			
Copper	390	1,300	10.0	33.0
Gold	12	170	0.6	16.0
Silver	7	120	0.5	10.0
Lead	85	170	11.0	17.0
Zinc	15	27	3.0	6.0
	-------Discounted present value ($ million/year)[c]----------			
Copper	240	1,100	3.8	16
Gold	5	63	0.3	8
Silver	4	50	0.3	5
Lead	46	110	4.4	7
Zinc	9	16	1.1	3
	------------Annualized costs ($ million/year)[d]------------			
Copper	35.1	190	0.50	2.4
Gold	0.8	9	0.04	0.9
Silver	0.6	10	0.04	0.6
Lead	6.5	14	0.57	1.2
Zinc	1.4	4	0.20	0.5

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[a] Maximum means the maximum cost for a facility in the EPA data base.

[b] Lifetime cost (1985 dollars), not discounted, including: closure and 30 years post-closure costs for existing wastes; opening and managing a new waste management facility for 15-year future operations; closure at end of 15th year; post-closure management for 30 years.

[c] Discounted present value of lifetime costs, as listed in note (a). Real discount rate of 9.0%.

[d] Lifetime costs annualized over 15-year future mine production period using a real discount rate of 9.0%.

Source: Estimated by Charles River Associates 1985a.

higher than the average. For example, in the zinc and copper segments, a high-cost facility would face costs about three times higher than the average. For silver and gold, the costs of meeting the Scenario 1B RCRA regulation would be on the order of 15 times the industry average.

Differences between the two scenarios are equally striking. Facilities employing RCRA cap and liner controls (Scenario 1B) would have 5 to 40 times more RCRA-related waste management costs over their lifetime than if they employed only the maintenance and monitoring functions estimated for Scenario 4B.

5.2.4 Potential RCRA Costs Relative to Mine Production Costs

Comparing potential facility compliance costs to total mine production costs provides insight on the possible effect of RCRA Subtitle C regulations on individual mine economics. Table 5-7 shows potential incremental compliance costs per unit of mine product (typically, concentrated ore) and potential incremental RCRA costs as a percentage of the segment's average current total direct production cost. Potential cost impacts of hazardous waste regulation for an average mine for the low-cost Scenario 4B range from about 1 to 5 percent of total production costs for the five metal segments. By contrast, for the high-cost Scenario 1B, potential incremental RCRA regulation costs would range from about 20 to 120 percent of current total direct product costs, on the average, for individual facilities in the five segments.

The high-cost mines again would experience impacts significantly greater than the average. In Scenario 1B, EPA estimates that the high-cost facilities in all five segments would face potential RCRA compliance costs in excess of

Table 5-7 Potential Incremental RCRA Compliance Costs Relative to Facility Production Costs

	Cost per unit of product[a] (Dollars per metric ton)		Percent of direct product cost[a]	
	Average for affected facilities	High-cost facility	Average for affected facilities	High-cost facility
Low-cost scenario (4B)				
Copper	$ 17.6	$ 44.1	1.7%	4%
Gold	5,625.5	29,466.9	1.1%	6%
Silver	267.9	1,071.5	2.5%	10%
Lead	5.4	15.4	1.9%	5%
Zinc	28.7	57.3	5.2%	10%
High-cost scenario (1B)				
Copper	$ 1,212.5	$ 3,417.1	120%	340%
Gold	117,867.6	267,881.0	23%	54%
Silver	4,286.1	16,608.6	40%	160%
Lead	60.6	253.5	21%	88%
Zinc	209.4	319.7	39%	58%

[a] Direct costs of mine product are based on sector averages of current cash operating costs for facilities, as estimated by Charles River Associates for EPA. Costs do not include facility-level capital investment, depreciation, interest expense, or corporate overhead.

Source: Estimated by Charles River Associates, 1985a.

50 percent of their total direct production costs. Even under the low-cost Scenario 4B, estimates for the most-affected facilities in each of the five segments range between 5 and 10 percent of total mine production costs.

SECTION 5 FOOTNOTES

[1] Charles River Associates 1985a.

[2] This data base was originally developed by Charles River Associates.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 SCOPE

As detailed in Section 1, this report covers the waste generated from the extraction and beneficiation (concentration) of metallic ores, phosphates, and asbestos and the mining of uranium. Although these selected mining segments include only about five percent of the 13,000 active mining operations in the U.S. noncoal mining industry, the facilities covered in this report generate over 90 percent of the total waste material produced by all noncoal mines.

6.2 SUMMARY OF CONCLUSIONS

The Agency's conclusions from the studies presented in this report are summarized under major groupings paralleling the organization of the report, namely: (1) Structure and Location of Mines, (2) Waste Quantities, (3) Potential Hazard Characteristics, (4) Evidence of Environmental Transport, (5) Evidence of Damage, (6) Management Practices, and (7) Potential Costs of Regulation.

6.2.1 Structure and Location of Mines

Because of the wide availability of detailed and comprehensive information published by the U.S. Bureau of Mines and supplemented by data from industry trade associations, EPA's conclusions on the numbers, sizes, and locations of U.S. mines are based solely on these standard sources.

1. There is a relatively small number of mines in the segments under consideration in this study. Fewer than 500 mine sites (1985)

extract and concentrate metals, phosphates, and asbestos in the U.S. (excluding gold placer mines). Of these, about 290 (62 percent) are accounted for by the precious metals (gold, silver) and uranium segments alone.

2. There is a great diversity in the size of mining facilities. This is true whether one measures size in terms of property area, product tonnage, total volume of material handled, or waste generated. The largest mine sites (e.g., in the iron ore, copper, and phosphate segments) are measured in terms of square kilometers, and each one handles more than 10 million tons of material per year. By contrast, about 25 percent of the mines included in this study handle less than 1,000 tons per year.
3. There is also great diversity in the unit value of product mined. In the segments studied, this value varies from $20 per ton for crude phosphate to over $10 million per ton for gold.
4. With few exceptions (notably in the precious metals) the trend has been toward a reduction in the number of active mines in most segments and an increase in the number of inactive mines, closed or abandoned mines.
5. Metals, phosphate, and asbestos mining are very heavily concentrated in a few States and EPA Regions. Over 90 percent of the mine sites in the industry segments are west of the Mississippi River, and over 60 percent are concentrated in just 10 States with 20 or more mines each. Eight of these 10 States are in the Rocky Mountain and Great Basin regions (EPA Regions 6,8,9, and 10), where almost 65 percent of U.S. metal mines are located.

6. These mines are generally located in areas of low population density. They are often, although not always, located several kilometers from population centers and the sources of public water supplies (reduced human exposure impact).

6.2.2 Waste Quantities

The conclusions summarized in this section are derived primarily from EPA studies. Waste quantity estimates are based largely on primary data from the U.S. Bureau of Mines on ore concentration and productivity for individual mine properties or producing regions, supplemented by EPA-sponsored engineering studies and extrapolations. These studies and extrapolations are described in detail in Section 4.1 and Appendix B to this report. Waste types and quantities reported here include all mine overburden and waste rock (mine waste), material subject to dump (copper) or heap (gold and silver) leach operations, and tailings from beneficiation processes.

1. Annual aggregate waste quantities for these segments are large by any standard. Mines in the metal, phosphate, and asbestos segments produce about 1.0 to 1.3 billion metric tons per year of various types of mining waste. By contrast, total municipal "post-consumer" solid waste totals 150 million tons and total industrial hazardous waste for all industries other than mining totals about 250 million tons per year.
2. Total waste accumulated by all active, inactive, and abandoned mines since 1910 is estimated at 50 billion metric tons.
3. Ratios of waste to product in mining vary considerably, but are generally substantially higher than for any other industries. The percentage of marketable ore obtained from mining operations ranges from 60 percent of the material excavated at iron ore mines to

30 percent at surface copper mines and 7 percent at surface uranium mines. By contrast, 50 percent or more of all the harvested wood in the forest products industry becomes marketed wood or paper products, and only a very small percentage of crude oil remains as waste in the production of fuels and petrochemicals.

4. Total waste quantities vary greatly among facilities in mining. As noted earlier, 25 percent of the mines in this study are rated at less than 1,000 tons per year of total material handled (well within the waste generation range of facilities in, say, the pulp and paper or petrochemicals industries.) On the other hand, the larger facilities in the copper, iron, and phosphate mining segments handle more than 10 million tons per year each. Any one of these larger individual facilities will generate more total waste in the normal course of its activities than all firms together in almost any other industry.

5. Aggregate waste in mining is concentrated in a few segments and a few states. Seventy percent of the 1.3 billion tons of total mining waste (1982) was generated in two segments, copper (39 percent) and phosphates (31 percent). This suggests that almost 23 percent of all mining waste is generated in Arizona (68 percent of copper production), and that almost 23 percent of this waste is generated in Florida (74 percent of U.S. phosphate production). An additional 14 percent of all mining waste was contributed by iron mining (largely in Minnesota), and 6 percent by uranium (Colorado, New Mexico, Utah, and Wyoming). All remaining nonfuel mining segments together generated the remaining 10 percent of total mining industry waste.

6.2.3 Potential Hazard Characteristics

Data on waste hazard characteristics are the result of extensive EPA sampling and analysis studies, as described in Section 4, and are based on samples from 86 extraction and beneficiation sites.

1. Of the 1.3 billion metric tons of waste produced each year, only 61 million metric tons (5 percent) of copper, gold, silver, lead, or zinc wastes exhibited RCRA hazardous characteristics. These include 50 million metric tons of corrosive (pH less than 2.0) copper leach dump waste and 11 million metric tons of gold, silver, lead, or zinc overburden or tailings that were EP toxic (generally for lead). EP toxicity test leachates from gold, silver, lead, zinc, uranium, and other metal wastes had toxic metal concentrations between 20 and 100 times the levels set by the National Interim Primary Drinking Water Standards; however, these were below the threshold of being a hazardous waste.
2. Twenty-three million metric tons per year of gold and silver wastes are potentially hazardous because they have been leached using a cyanide solution. These cyanide wastes include those metal recovery wastes previously listed as hazardous, as well as heap leaching wastes, but do not include copper mill tailings or other mill tailings with low (less than 10 mg/liter) concentrations of cyanide from flotation circuits.
3. Copper leach dump material (182 MMT) and copper mill tailings (95 MMT) may be hazardous. In addition to the 50 MMT/year of copper leach dump waste estimated to be corrosive, the remaining 132 MMT of this waste may also pose potential hazards because of its low pH and relatively high concentrations of toxic metals. Copper leach dump

wastes are potentially hazardous even when the pH level of their leachate is not below 2.0, because their leachate is still quite acidic and contains toxic metals. However, toxic constituents in and hazardous characteristics of these wastes do not exceed EPA's established criteria. Similarly, copper, gold, silver, and lead mill tailings containing high (greater than 1 percent) concentrations of pyritic material and low (less than 1 percent) concentrations of carbonate buffers have a high potential for forming and releasing sulfuric acid.

4. Naturally occurring radioactivity (radium-226) levels in excess of five picocuries per gram (pCi/g) has been estimated for 443 million metric tons/year of wastes from sites generating uranium mine waste and phosphate wastes. Use of an alternative radioactivity measure of 20 pCi/g yields an aggregate estimate of about 93 million metric tons/year of radioactive waste, most of which is uranium mine waste.
5. Four asbestos mines generate about 5 million metric tons per year of waste containing high (greater than 1 percent) asbestos fiber content. Only asbestos mines were tested in the current study for asbestos fibers.
6. EPA's solid waste sampling thus far has not found any hazardous characteristic in waste from the iron ore, molybdenum, or certain minor metals segments. The Agency tested wastes from virtually all metal mining segments but did not test wastes from all mineral mining segments, on the assumption that these wastes are unlikely to be hazardous.
7. Based on the above, the Agency concludes that as many as 80 percent of the metal mining facilities and perhaps 56 percent of the waste

generated could be considered potentially hazardous to human health or the environment under some circumstances. Generally, a given mine site will exhibit only one primary problem: EP toxicity, cyanide contamination, corrosivity/acidity, radioactivity, or asbestos, according to the Agency's sampling results.

6.2.4 Evidence of Environmental Transport of Potentially Hazardous Constituents

The potentially hazardous constituents and characteristics of various mining wastes can be transported from the location of storage or disposal to possible receptors by various combinations of surface water flow, seepage into ground water and ground-water flow, and wind currents. The Agency's studies in this area focused primarily on efforts to evaluate environmental transfer to and through surface and ground water. Study methods included both a literature search and a limited field monitoring study at eight selected mine sites (one only for surface water) over a 6- to 9-month monitoring period.

1. Ground-water monitoring is difficult, expensive, and has seldom been conducted at mine sites on a comprehensive basis. Because of complex geologic strata (presence of an ore body) and the extensive size of many mine properties, proper ground-water monitoring is technically difficult and costly. Historical practice in the mining industry has not required such monitoring. As a result, there is very little available information in the literature, and almost none on a complete or comprehensive basis. Most mines have no historical or contemporary ground-water monitoring information.
2. EPA's limited field monitoring shows environmental transfer of mine waste constituents to ground water, but not necessarily transfer of the EP toxic constituents of concern. Mine waste constituents--both indicator sulfates, chlorides, and some elements that could be

considered environmentally harmful--were shown to migrate from waste management areas to local aquifers. Short-term monitoring detected seepage from tailings impoundments (a copper, lead, phosphate sand, and two gold impoundments), a copper leach dump, and a uranium mine water pond. However, the EP toxic constituents of concern did not appear to have migrated at these sites during the short period of this study.

3. EPA's limited field monitoring generally did not show contamination of surface waters, but this may be the result of local circumstances of management, climate, and parameters monitored. Surface water contamination would not be expected downstream from an intact tailings impoundment. However, abnormally heavy precipitation could lead to releases or bypasses to protect the integrity of the impoundment dam.

4. Other scattered monitoring study data suggest mixed or inconclusive results regarding ground water and surface water contamination by constituents of concern. In Arizona, copper mine runoff has degraded surface water, and uncontained leachate from copper leach dump operations has degraded ground water by lowering pH and increasing concentrations of sulfates, copper, and total dissolved solids. Abandoned gold recovery operations that did not treat wastes before release can be the source of persistent cyanide contamination. Generally, contaminant plumes from tailings impoundments (other than uranium mill tailings impoundments) have not been studied.

6.2.5 Evidence of Damage

The Agency's conclusions on observed damage to the enviroment and health are based on an extensive survey of State government natural resource and health agency files through 1984 to obtain evidence of environmental incidents, followed by review and evaluation of the evidence obtained. All 50 States were surveyed by telephone, and 10 were visited. The mining sites reported on were not visited to observe or verify data obtained in the survey. Several hundred initially reported incidents were evaluated and eventually narrowed down to 20 verifiable cases of damages having substantial documentation. The damage survey was supplemented by reviews of published reports and National Priorities List (Superfund) data.

1. Damage cases are about equally distributed between catastrophic (sudden releases, spills) and chronic (seepage, periodic runoff) incidents.
2. Documented damage typically involves physical or chemical degradation of surface water ecosystems, often including fish kills or reduction in biota, but seldom involves direct effects on human health.
3. A number of incidents of damage caused by mining wastes at currently active sites in the phosphate, gold, silver, copper, and uranium industries have been well documented in several States, including Arizona, Colorado, Florida, Missouri, Montana, and New Mexico. Similar results have been documented at inactive sites, but abandoned and Superfund sites may have additional problems.
4. Damage to surface waters has often been reducible or reversible by use of modified waste management practices or other physical controls.

6.2.6 Waste Management Practices

The Agency's conclusions on waste management practices are based on literature reviews, site visits in conjunction with waste sampling, engineering design studies, and consultation with State regulatory agencies and mine company engineers.

1. Site selection, including both the mine property itself and the specific location of waste storage, treatment, and disposal activities, is perhaps the single most important aspect of environmental protection in the mining industry. The selection of the mine property is based primarily on the ability of the operation to produce a commodity (e.g., copper, gold, etc.) at a competititve price and a reasonable profit. The cost of transporting waste via pipeline, conveyor, or truck to the disposal site is an important variable in determining the profitability of the mine, because of the large volume of material moved at most mines.
2. The potential for waste utilization as a solution, or even as a significant contributor, to waste management in most mining segments is extremely limited.
3. There are few major innovations under development that would lead to major changes in mine production processes or waste management practices.
4. The difference between "best practice" and typical practice is often significant among mines in many major segments. These differences are related to both voluntary management practices and variations in State regulations.
5. Within known technological options, there appear to be major opportunities for process modifications, some source separation of wastes, treatment of acids and cyanides, and, possibly, controlled release of certain effluents that could significantly reduce damage potentials in certain contexts.
6. Many waste management practices being applied to hazardous waste in

other industries--most notably caps and liners--have not been attempted for mining wastes.

6.2.7 Potential Costs of Regulation

The Agency conducted engineering cost analyses, using several different hypothetical regulatory scenarios, for a sample of 47 actual sites, and then extrapolated these costs to the universe of facilities in the copper, lead, zinc, silver, and gold mining segments. EPA's approach, methods, and assumptions are discussed briefly in Section 5 and in Appendix B.

1. For five metal mining segments, total annualized costs could be substantial, but vary considerably across different hypothetical regulatory scenarios. Annualized costs range from $7 million per year (for a scenario that emphasizes primarily basic maintenance and monitoring of RCRA hazardous wastes) to over $800 million per year (for a highly unlikely scenario that approximates a full Subtitle C regulatory approach emphasizing cap and liner containment for an expanded range of potentially hazardous wastes).
2. Almost 60 percent of total projected annualized costs at operating facilities can be attributed to the management of waste accumulated from past production.
3. Costs would vary greatly among segments. Some segments may not be affected at all (iron, molybdenum), because their waste streams apparently do not contain hazardous constituents. Total lifetime costs for affected segments could range from $45 million for zinc up to $8.3 billion for copper (for the highest cost scenario).
4. Costs would vary greatly among mines within segments. Incremental compliance costs, as a percentage of direct product cost, could vary as much as 25:1 among facilities within a given segment. Factors

affecting these differences include geography, ore grade, past waste accumulation, percentage of waste with hazardous characteristics, and process and waste management practice efficiencies.

6.3 RECOMMENDATIONS

Section 8002(f) of RCRA requires EPA to conduct a study of the adverse effects of mining waste and to provide "recommendations for Federal...actions concerning such effects." Based on our findings from this study, we make several preliminary recommendations for those wastes and industry segments included in the scope of the study. The recommendations are subject to change based on continuing consultations with the Department of the Interior (DOI) and new information submitted through the public hearings and comments on this report. Pursuant to the process outlined in RCRA §3001(b)(3)(C), we will announce our specific regulatory determination within six months after submitting this report to Congress.

First, EPA is concerned with those wastes that have the hazardous characteristics of corrosivity or EP toxicity under current RCRA regulations. EPA intends to investigate those waste streams. During the course of this investigation EPA will assess more rigorously the need for and nature of regulatory controls. This will require further evaluation of the human health and environmental exposures mining wastes could present. EPA will assess the risks posed by various types of mining waste sites and alternative control options. The Agency will perform additional waste sampling and analysis, additional ground-water or surface water monitoring analysis, and additional analysis of the feasibility and cost-effectiveness of various control technologies.

If the Agency determines through the public comments, consultation with DOI and other interested parties, and its own analysis, that a regulatory strategy is necessary, a broad range of management control options consistent with protecting human health and the environment will be considered and evaluated. Moreover, in accordance with Section 3004(x), EPA will take into account the "special characteristics of such waste, the practical difficulties associated with implementation of such requirements, and site-specific characteristics...," and will comply with the requirements of Executive Orders 12291 and 12498 and the Regulatory Flexibility Act.

Second, EPA will continue gathering information on those waste streams that our study indicates may meet EPA's criteria for listing--dump leach waste, because of its high metal concentrations and low pH, and wastes containing cyanides. Although these waste streams are potential candidates for listing as hazardous wastes, we need to gather additional information similar to the information gathered for the rulemaking for corrosive and EP toxic wastes. When we have gathered sufficient information, we will announce our decision as to whether to initiate a formal rulemaking. If the Agency finds it necessary to list any of these wastes, we will also develop appropriate management standards in the same manner as those for corrosive and EP toxic wastes.

Finally, EPA will continue to study radioactive waste and waste with the potential to form sulfuric acid. The Agency is concerned that radioactive wastes and wastes with the potential for forming acid may pose a threat to human health and the environment, but we do not have enough information to be able to conclude that they do. We will continue to gather information to determine whether these wastes should be regulated. If EPA finds that it is necessary to regulate these wastes, the Agency will develop the appropriate measures of hazard and the appropriate waste management standards.

SECTION 7

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APPENDIX A

SUMMARY OF MAJOR WASTES FROM THE MINING AND PROCESSING OF OIL SHALES

APPENDIX A

SUMMARY OF MAJOR WASTES FROM THE MINING AND PROCESSING OF OIL SHALES

A.1 INTRODUCTION

It is projected that the first U.S. commercial oil shale plant (Union Oil's 10,000 bbl/day Long Ridge facility) will come on line in 1985.[1] Other larger plants are scheduled to start production between 1987 and 1994, and many of these may be supported by the Federal Government through the U.S. Synthetic Fuels Corporation. It has been estimated that in the western United States alone, mining and processing volumes could eventually reach 1 million metric tons per day.

The mining methods that will be used include room-and-pillar, lane-and-pillar, open pit, and vertical-modified-in-situ (VMIS); production rates are expected to range from about 12,000 to approximately 150,000 metric tons per day. Downstream, or auxiliary, operations will include oil upgrading, gas cleanup, and raw and wastewater treatment, but the processes that will be used in these operations are more diverse and less well defined than mining and retorting operations.

Although the types and quantities of solid wastes that will be produced by oil shale plants are not well defined at this time, it is estimated that production of the volume of oil shale anticipated (1 million metric tons per day) will require the disposal of 810,000 metric tons of retorted shale per day, 66,000 metric tons of raw shale fines per day, and over 3,000 metric tons per day of spent catalysts, treatment chemicals and sludges, and byproduct wastes. This would result in 300 million metric tons per year of wastes that must be disposed of in an environmentally acceptable and cost-effective manner.

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[1] The information in this Appendix has been summarized from "High Volume Wastes from the Mining and Processing of Oil Shales," written by E.R. Bates, U.S. Environmental Protection Agency, 1985, but not yet published.

Table A-1 shows the estimated quantities of solid waste that are projected to be produced by a commercial oil shale industry mining 1 million metric tons per day of raw oil shale. Some of these wastes, such as spent arsenic guard bed catalysts and API separator bottoms, will most certainly be hazardous. For the most part, these wastes will be produced in the large-scale solids-handling operations associated with most oil shale facilities. They include spent shale from retorting operations, dusts recovered from air pollution controls, and unused raw shale (sub-ore, fines, dust). Non-marketable byproducts, oily solids, scrap, and garbage are also considered major solid wastes.

A number of other solid wastes that may contain materials that are classified as hazardous will also be generated by commercial oil shale facilities. These include spent catalysts, used chemicals and sludges from gas cleanup operations, and water treatment sludges and slurries. Hydrogen plants, which produce hydrogen for hydrotreating the crude shale, will be the major source of a variety of spent catalysts. As listed in Table A-1, these catalysts may include Co-Mo and ZnO catalysts from the hydro-desulfurizer (HDS) unit; Ni-base, Fe-Cr, and Cu-Zu catalysts from the reformer; Ni-base catalysts from the methanator; and arsenic guard bed and hydrodenitrification (HDN) catalysts from the hydrotreater. However, as can be seen from the individual quantities and totals listed, discrepancies exist in the estimates of quantities that may be produced.

Table A-1 Relative Quantities of Solid Wastes Potentially Generated by the Oil Shale Industry

Type of waste	Mean Quantity of Waste Produced (metric tons/ million metric tons of shale mined)	Standard Deviation (metric tons/ million metric tons of shale mined)	Percent Uncertainty[a] (%)	Data Points (N)
Major Solid Wastes:				
Spent Shale	810,000	24,000	3.0	8
Raw Shale Rejects	66,100	12,200	18.5	8
Off-Spec Byproducts	1,180	170	14.4	4
Oily Solids	340	180	52.9	5
Scrap and Garbage	40	20	50.0	4
TOTAL[b]	880,000	40,000	5.0	-
Spent Catalyst Generation:				
Hydrogen Plant[c]	3.50	0.25	7.1	5
HDS Unit	0.96	0.18	18.8	4
Co-Mo	0.41	0.20	48.8	3
ZnO	0.65	0.17	26.2	4
Reformer[c]	3.01	-	-	2
Ni-base	0.81	-	-	2
Fe-Cr	1.23	0.24	19.5	4
Cu-Zn	1.64	-	-	2
Methanator	0.34			
Ni-base	0.34	0.02	5.9	4
Hydrotreater[c]	20.5	2.8	13.7	4
Guard Bed	15.6	2.0	12.8	4
HDN	1.45	-	-	2
TOTAL [c]	26.9	5.1	19.0	7

Table A-1 (Continued)

Type of Waste	Mean Quantity of Waste Produced (metric tons/ million metric tons of shale mined)	Standard Deviation (metric tons/ million metric tons of shale mined)	Percent Uncertainty[a] (%)	Data Points (N)
Gas Cleanup Processes:				
Activated Alumina	1.86	0.90	48.4	3
Co-Mo	0.11	-	-	2
Al_2O_3	0.13	-	-	2
DEA	0.60	-	-	1
Stretford Chemicals	1.87	0.58	31.0	3
TOTAL[c]	2.06	0.54	26.4	6
FGD Sludges	2,250	1,500	66.0	3
Water Treatment Sludges and Slurries:				
Biological Sludges	545	-	-	3
Sludges & Floats	6,900	-	-	1
Tank Bottom (WWT) Sludges	150	-	-	2
API Separator Bottoms	20	-	-	2
API Float	2	-	-	1
Raw Water Treatment Sludges & Floats	72	-	-	1

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[a] Percent uncertainty is the relative standard deviation.

[b] Included in this total are 2340 million metric tons of solid wastes not broken out separately above.

[c] Quantities in subcategories do not equal the total for these categories. These discrepancies result from the small data base, differing information from various projects, and uncertainty since these plants have not yet been operated. For a full explanation, see Heistand 1985.

Source: Heistand 1985

Because planned gas cleanup operations are more diverse and less well defined than oil upgrading, the amounts of chemicals used (activated alumina, Co-Mo, Al_2O_3, DEA, and Stretford chemicals) and flue gas desulfurization (FGD) sludges from gas cleanup processes are more difficult to estimate, and a solid statistical analysis of the mean factors listed in Table A-1 is not feasible. Information on chemicals other than activated alumina and the Stretford chemicals is incomplete, and several projects plan to use more than one of the gas cleanup chemicals listed. The estimated total of used chemicals generated from fuel gas cleanup is about 2.1 metric tons per million metric tons of oil shale mined. While FGD has been suggested as an alternative to fuel gas cleanup processes, the amounts of FGD chemicals such as calcium sulfate or gypsum are quite high, with mean quantities projected to be 2,250 metric tons per million metric tons of shale (Heistand 1985).

Sludges and slurries will be generated in raw and wastewater treatment in commercial oil shale facilities. Because the exact composition and amounts of the wastewaters requiring treatment are not well defined and many of the resulting materials may be used on site, only limited information is available for estimating the volume of water treatment sludges and slurries (Heistand 1985). The dry weights of these wastes are listed in Table A-1.

A.2 POTENTIAL DANGERS TO HUMAN HEALTH AND THE ENVIRONMENT

Oil shale facilities will produce large volumes of solid wastes that have only a limited reuse potential. In some cases, spent catalysts may be reclaimed and recycled back into the process. Elemental sulfur, which can be removed by some air pollution control technologies, has some market potential although the presence of trace impurities may constrain its use. Hazardous wastes such as some spent catalysts and sludges will be disposed of in licensed hazardous waste facilities.

The catalyst that is of particular concern in oil shale upgrading is the arsenic guard bed catalyst. Raw shale oil contains significant amounts of arsenic (15 ppm range) that must be removed prior to upgrading and refining. Arsenic is removed by the arsenic guard bed catalyst, which must be replaced periodically and reclaimed or disposed. However, no facilities currently exist to reclaim the catalyst, and environmentally safe disposal of this spent catalyst, which may contain 20 percent arsenic as well as other contaminants, and be pyrophoric (tend to autoignite), may be difficult. As noted in Table A-1, approximately 15 metric tons of spent arsenic guard bed catalyst will be produced for each million metric tons of shale mined.

Other dangers to human health and the environment posed by oil shale mining and processing may result from the long-term effects of the onsite disposal of millions of tons of retorted oil shale, raw oil shale waste, and other process wastes. These hazards include the following:

- Auto-oxidation/autoignition
- Leaching
- Mass failure.

A.2.1 Auto-oxidation/Autoignition

Auto-oxidation resulting in autoignition may be a serious problem if raw shale fines and/or carbonaceous spent shales are not disposed of in a manner that minimizes this hazard. If oil shale disposal sites are not properly designed they could autoignite, releasing large quantities of pollutants such SO_2, NO_x, H_2S, CO_2, trace elements, and hydrocarbons. Combustion could also impair pile stability, resulting in disposal pile failure and/or acceleration of the leaching process. EPA has recently conducted tests to assess the potential for autoignition of waste raw oil shale fines and retorted oil shales (EPA 1984). The results of these tests indicate that raw shale fines have an autoignition potential similar to that of bituminous coals, while retorted shales appear to be less reactive.

A.2.2 Leaching

High inorganic salt loading and possible organics in leachates from raw shale fines or spent shale could have potentially significant impacts on ground-water supplies and on surface waters that supply the water needs of millions of people. Because the composition of retorted oil shales varies based on the properties of the raw shale feed and the retorting process used, the composition of any leachates from retorted shale disposal sites will vary depending on the properties of the retorted shale and on other wastes disposed of with the retorted shale, such as wastewaters for cooling/wetting and treatment sludges.

The available data indicate that even if raw and retorted shale wastes are not defined as hazardous under RCRA, the leachates from these wastes are high in dissolved salts as well as other contaminants and could have a serious impact on surface and ground water if significant amounts of leachate are produced. The amount of leachate produced will depend to a large extent on site-specific characteristics and the disposal controls employed. Because billions of tons of retorted oil shale may eventually be produced, the cumulative impact on water quality could be very great.

A.2.3 Mass Failure

Retorted oil shale disposal sites will be the largest solid waste disposal sites ever constructed. A typical 50,000 bbl/day surface retorting plant will produce about 450 million cubic feet/year of solid waste, which would cover an area of about 3.5 square miles to a depth of 150 feet over an operating plant life of 30 years (USEPA 1980). Mass failure of one of these fills could cause extensive property damage and threaten lives. Failure of even one of the several disposal piles proposed could destroy downstream reservoirs; threaten shale oil upgrading, storage, and loading facilities; and deposit millions of tons of leachable retorted shale in the Colorado River and/or its tributaries.

The most likely cause of a disposal site failure is saturation of the waste pile and/or liquefaction of the pile bottom leading to slippage. Moisture that could contribute to this problem might result from wastewaters, precipitation and infiltration, ground-water intrusion into the pile, or surface streams routed over or through the disposal site.

A.3 DISPOSAL ALTERNATIVES

A.3.1 Alternatives for Minimizing Environmental Impacts

Oil shale operations will result in significant land disturbances on and near the development site. Use of the land required for access to the site for mining, processing facilities, and waste disposal will permanently modify the terrain and influence the ecosystem by causing changes in the vegetation and habitat. Local aesthetics will also be affected.

The most significant impacts on the environment will probably result from the disposal of solid shale wastes, which will remain long after a mine has been depleted and the processing facility has closed down. A major factor to consider in solid waste disposal is the surface- and ground-water regime of the site. While a waste landfill should blend in cosmetically with the surroundings, it must also be sufficiently isolated from the surrounding strata to protect the hydrologic environment. Other factors that influence waste disposal and may contribute to the extent of environmental impacts are the size and duration of the oil shale operation and the mining and retorting technologies used. Because a substantial amount of raw shale will need to be mined and processed to produce oil, the processed shale will be the major waste produced by oil shale processing and its disposal will be the primary environmental issue.

The physical and chemical properties of the processed shale as well as the geology and hydrology of the site will be the determining factors in selecting disposal and reclamation approaches. Every retorting method produces shale that is unique and every development site has features not found elsewhere, and therefore their combination should be analyzed on an individual basis. The physical and chemical characteristics of the processed shale will be determined by the source of the raw shale, its particle size after crushing and retorting, and the temperature of the retorting.

There are primarily two types of processed shale--carbonaceous and burned (decarbonized). Carbonaceous processed shales are produced by indirect retorting in which residual coke on the retorted material is not incinerated. Examples of this type of retorting are the TOSCO II and Union B processes. Burned shales originate either from direct-heat processes, such as Paraho and Modified in Situ (MIS), in which the air is introduced in the retort to cause combustion of the residual carbon or from combination-mode processes, such as Lurgi, Superior, and Union C, in which the retorting primarily occurs in the indirect mode, but the residual coke on the procesed shale is incinerated in a separate stage.

The mining and processing of oil shale actually result in an increase in the volume of shale. In-place density of the raw shale is approximately 2.16 g/cm^3, but it is only practical to compact the processed shale to about 1.5 to 1.6 g/cm^3. Even after losing about 20 percent of its original weight, the shale after retorting will occupy about 10 to 15 percent more volume than it originally occupied. This will be an important factor when considering different approaches for the disposal of processed shale.

Processed shale moisturizing will be essential in disposing of the processed shale and will serve several functions. The processed shale will emerge from most retorts at elevated temperatures, requiring cooling and/or moisturizing prior to handling and disposal. Transporting the processed shale to the disposal area will involve extensive materials handling and transfer that will be potential sources of airborne particulates, and these particulate emissions can be minimized by moisturizing and using covered transport. Perhaps the most significant advantage to moisturizing is that it facilitates proper compaction and cementing of the processed shale, which will allow the disposal of the maximum quantity of material in a given space and will provide greater stability to a waste landfill.

Several alternatives are available for the disposal of shale processing wastes. The disposal approaches available are surface disposal (canyon or valley fill, surface pile), open pit backfill, underground mine backfill, in situ retort abandonment, and, the least likely, commercial utilization of wastes. The approaches or combinations of approaches used will depend largely on site-specific features, the mining and retorting methods used, the surface and subsurface hydrology of the area, and the properties of the processed shale resulting from the retorting methods used. These disposal alternatives are discussed in the following paragraphs.

A.3.2 Surface Landfills

The disposal of wastes in a valley or canyon near the plant site may be the approach preferred by many oil shale developers. This selection is influenced by the terrain of oil shale areas where large valleys and/or canyons are available on development sites to accommodate the wastes generated. Proper reclamation can allow for the landfill to be blended into the surrounding terrain.

The advantages of this type of landfill are that the surface area needing to be reclaimed or revegetated would be reduced and the bulk of the material would be protected from the weather. However, water contamination resulting from run-on and runoff and mechanical failure resulting from mass movement and slippage are two disadvantages of this method that must be considered. If the disposal area is flat, the landfill will need to be built above the surface as a pile, in which case it will not blend into the surrounding environment and will be visible from a distance. Although surface waste piles may limit run-on and runoff problems, pile-up operations are more difficult and involve more skill than valley fill operations, and exposure of landfills to wind and water may result in excessive erosion.

The disadvantages of surface landfills as a disposal alternative can be summarized as follows:

- Exposure to rain, snow, and wind may result in erosion of the waste pile and mechanical failure.
- Waste particles disturbed by weather may become airborne or be carried into surface- or ground-water supplies in runoff from the waste pile.
- Surface landfills may not blend into the surrounding terrain.

A.3.3 Open Pit Backfilling

Open pit backfilling is a type of surface landfill that may be an alternative for open pit mining operations. Backfilling requires that the overburden, sub-ore, and processing wastes generated during the first 20-30 years be temporarily stored or permanently disposed of in another location so that they do not inhibit mining operations. Once the mine pit has been sufficiently developed, the waste can be disposed of in the non-active pit areas while mining continues on the active faces. After the project is shut down, some of the initial waste stored outside the pit can be returned to the mine, but approximately 20-30 percent of the total mined-out volume would still need to be permanently disposed of outside the pit.

The advantages of open pit mining and backfilling are that they allow for greater resource recovery than underground methods and the erosion potential is greatly reduced because the bulk of the material will not be exposed to the weather. In addition, if backfilling is complete, the land can be brought back to its original contour. The disadvantages of open pit backfilling include the following:

- Additional disposal is required outside the open pit.
- A depression in the land surface may result from compaction and settling of materials backfilled into the pit, allowing water collection and possible waste pile infiltration.
- Ground water may be contaminated, particularly if the pit intersects an existing aquifer.

A.3.4 Underground Mine Backfilling

Returning the processed shale to the underground mine is an attractive disposal approach and several underground backfilling methods are available, although none has been tested on a large scale. Slurry backfilling via pipelines is practical for processed shale disposal but requires large amounts of water. Transportation by conveyors or trucks and subsequent compaction using standard machinery is another method. Pneumatic transport is also a possibility.

The advantages of using underground mine backfilling are that the waste would be protected from the weather, erosion potential would be diminished, and the need for surface reclamation and revegetation would be reduced. Also, the danger of mine subsidence would be significantly reduced.

The disadvantages inherent in this disposal alternative include the following:

- The logistics of simultaneous mining and backfilling operations may be complex, requiring substantial above-ground disposal capacity before backfilling can commence.
- Because of the difficulties in backfilling, coupled with the expansion volume caused by mining, crushing, and retorting and difficulty in achieving a high degree of compaction in underground mines, perhaps only 60 percent of all processed shale can be accommodated.
- Release of volatiles from retorted and backfilled shales may create a fire hazard or otherwise endanger workers.

A.3.5 In-Situ Retort Abandonment

Although in-situ retorting processes do not involve surface handling and disposal of processed shale, the retorted mass underground is waste that must be managed. Although spent retorts may appear in some ways to be equivalent to backfilled wastes in underground mines, there are important differences.

With in-situ retorts, it is not possible to control the amount and placement of material, and the extent of ground-water seepage into the retort cannot be determined or managed until after the retort field is abandoned and ground-water levels are no longer depressed.

The primary concerns associated with the abandonment of in-situ retorts are ground-water infiltration, the retention of heat in the retorted mass, and the creation of a combustion hazard caused by air leaking into the retort.

A.3.6 Potential Utilization of Wastes

Retorted oil shale, particularly decarbonized shales, raw shale fines, spent catalysts, elemental sulfur, and biological treatment sludges may have a limited potential for use on site. Decarbonized western oil shales have cementing properties similar to those of low-grade commercial cement and may be used as a cement substitute. Raw shale rejects and fines from mining and raw shale preparation could be processed by some types of retorts or formed into briquettes for processing by other retort facilities. Some spent catalysts could be reclaimed and reused in the upgrading process, although no facilities presently exist to reclaim them. Some air pollution control technologies remove elemental sulfur, which may have a limited market value if it is not contaminated by impurities. Biological treatment sludges may be useful on site as soil conditioners for revegetation if they do not contain significant quantities of harmful contaminants.

Unfortunately, even if each of these wastes is used to the maximum extent possible, it will not have a significant impact on the total amount of solid oil shale waste requiring disposal.

A.4 CONTROL TECHNOLOGIES

The following discussion of the control technologies applicable for oil shale waste disposal is derived from EPA's Pollution Control Technical Manual (1983) for TOSCO II oil shale retorting and summarizes the major control technologies for preventing contamination of surface- and ground-water supplies by runoff or leachate, for preventing the generation of dusts, and for preventing mass failure of a surface landfill. Selecting and applying the appropriate control technologies must be based on site- and plant-specific features, and controls must be integrated into the overall disposal design. The following sections specify control technologies and practices in the following areas:

- Surface hydrology
- Subsurface hydrology
- Surface stabilization.

(Control technologies for oil shale wastes are similar to those mitigative measures specified in Section 3 of this report.)

A.4.1 Surface Hydrology Control Technologies

Solid waste management practices in the area of surface hydrology entail the handling of surface waters on and around the disposal facility to prevent surface streams and precipitation from running onto the waste pile and to keep contaminated waters (runoff, leachate) from infiltrating natural waters. Surface hydrology control technologies that are applicable to surface landfills include run-on diversion systems, runoff collection systems, and runoff/leachate collection ponds.

A.4.2 Subsurface Hydrology Control Technologies

The technologies and practices in the area of subsurface hydrology involve handling ground-water seepage under landfills to prevent infiltration of the pile. These technologies also prevent leachate from the pile from contaminating ground water. These include liners and covers, leachate collection systems, and ground-water collection systems.

A.4.3 Surface Stabilization Technologies

Control technologies in the area of surface stabilization address the disturbed land surface and the problems associated with the disposal and reclamation of waste material. They include dust controls, such as the use of water and binders and the paving of haul roads, and erosion controls, such as mulching, revegetation, and designs that provide slope stability.

A.5 CONCLUSIONS

The oil shale industry will produce unprecedented volumes of solid waste consisting primarily of retorted oil shales, raw oil shale fines, overburden and subgrade ore, wastewater, and smaller quantities of known hazardous wastes. Although most known hazardous wastes will be disposed of in licensed disposal or recycling facilities, a majority of the solid wastes produced will be disposed of on or close to the plant site. If this large volume of wastes is not properly managed, it may produce leachates that could contaminate the water supplies of millions of people, pose an autoignition hazard, and, if a mass failure occurred, do extensive property damage and threaten lives.

Control technologies to prevent serious adverse impacts resulting from the disposal of billions of tons of oil shale wastes have been proposed, but their application to oil shale wastes on the scale required has not been demonstrated. Further, for these technologies to be effective they must be incorporated into highly technical and well-integrated disposal designs that are both site- and process-specific. Finally, there has been no experience in disposing of wastes having the characteristics and volume of those that will be generated by the oil shale industry.

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APPENDIX B

METHODOLOGY

APPENDIX B

METHODOLOGY

The most important empirical input for this study was derived from analyses of sampling results and information about active mines in the industry segments of concern. EPA's sampling methodology (described more fully in Section 4.1) involved sampling waste from at least one mine and mill in various mining region-commodity categories. These results were supplemented by sampling results from other studies so that EPA's waste samples would represent the full range of wastes and industries covered by this study. EPA's data base containing information about active mines in the industry segments of concern is described below. The Agency's methodology relied on contractor studies, EPA staff analyses, field and laboratory results, engineering estimates, and economic projections and trends. This appendix first describes EPA's data base, and then discusses how the Agency determined current industry control practices, estimated the amounts of waste involved, and extrapolated from waste volumes at individual mines to totals for all mining industry segments.

B.1 EPA'S DATA BASE

EPA compiled a data base of mines in the following industry segments as follows:

- Copper--13 mines;
- Gold--11 mines;
- Lead--7 mines;

- Silver--9 mines;
- Uranium--9 mines;
- Zinc--7 mines; and
- Phosphate--18 mines.

EPA had the following information about these mines:

- Name and location;
- Amount of product produced annually;
- Amounts and types of wastes existing on site and the amounts generated annually;
- Expected operating life of the mine; and
- Dimensions of waste management areas (e.g., area and perimeter of mine waste piles; depths, surface areas, height and width of berms of tailings impoundments; area and perimeter of heap/dump leach operations, etc.).

B.2 CURRENT INDUSTRY BASELINE PRACTICES FOR THE USE OF MITIGATIVE MEASURES

EPA assessed current industry baseline practices for the use of various mitigative measures as follows. The Agency assumed that mines located in states having regulations as stringent as RCRA requiring mines to have mitigative measures (e.g., ground-water monitoring, run-on/runoff controls, liners for tailings ponds, leachate collection and removal, pads for heap leach operations) currently used the required mitigative measures. In the case of closure, EPA assessed whether mine sites perform some or all of the procedures currently required by RCRA. Mines in states that do not have regulations requiring a certain mitigative measure, or requiring measures that are not as stringent as current RCRA requirements, were assumed not to be using a measure unless the Agency had specific knowledge that a measure was voluntarily being used at a specific mine in that state.

These assumptions were used to estimate the percentage of mines in various industry segments where sufficiently stringent mitigative measures are currently being used (see Section 3 of this report), and to determine baseline industry practices for the analysis of the economic costs of various regulatory scenarios (presented in Section 5 of this report).

B.3 ESTIMATED AMOUNTS OF POTENTIALLY HAZARDOUS MINING WASTE

EPA estimated the amount of potentially hazardous mining waste by type of hazard, industry segment, and type of waste (mine waste, tailings, leach waste) using EPA's waste sampling results (presented in Section 4.1), site-by-site estimates of the amount of mining waste at operations at sites represented in the data base described above, and estimates of the total amount of waste generated by each mining industry segment.

EPA's first step in estimating the annual generation of potentially hazardous mining waste was to project the number of mines active in 1985, the amount of waste generated annually, and the amount of waste existing at these mine sites in 1985. Because of the variability in the number of active mines in recent years, EPA projected past trends to arrive at 1985 estimates instead of using historical data from the most recent year for which such data were available. These projections are based on an extrapolation of mineral production levels and a review of the current operating status of mines, amounts of waste generated, and the amount of existing waste at the mines represented in the EPA data base. (These projections are presented in Table 4-17 of the report.)

EPA developed estimates of the amounts of specific mining wastes that may be potential candidates for listing (copper dump leach wastes, silver and gold heap leach wastes, silver and gold metal recovery wastes) based on annual generation data for each of these wastes. EPA estimated the amounts of waste that are hazardous because of their characteristics (i.e., corrosivity, EP toxicity, cyanide content, radioactivity, asbestos content, acid formation potential) based on the waste sampling and acid formation potential data for waste management operations represented in EPA's data base.

For sampled mines represented in the EPA data base, Table B-1 shows the percentage of all U.S. mining waste management operations and of all wastes generated by these operations in 1985, by industry segment. As this table shows, the data base used by EPA as the basis for this report on hazardous mining waste represents a considerable portion of the total number of mining waste operations and of all mining waste generated by these industry segments:

- For mine waste operations, the data base represents between 5 (gold industry) and 43 (lead industry) percent of all mine waste operations in each of the respective segments.
- For heap/dump leach operations, the data base represents between 17 percent (gold and silver industry segments), and 32 percent (copper industry) of all such operations in each of the respective segments.
- For tailings operations, the data base represents between 6 percent (gold industry) and 67 percent (copper industry) of all tailings operations.

In all cases, the percentage of waste represented in the data base is larger than the percentage of operations. For example, in the copper industry segment, 93 percent of all copper tailings waste but 67 percent of all copper

Table B-1 Percentage of Mines and Annual Amount of Waste Generated by Sampled Mines Represented in EPA's Data Base

Mining industry segment	Type of waste management operation	Percentage of all mining waste management operations in industry segment (1985)	Percentage of annual mining waste generated by industry segment in 1985
Copper	Mine waste	32	73
	Dump leach	32	38
	Tailings	67	93
Gold	Mine waste	5	35
	Heap leach	17	53
	Tailings	6	34
Lead	Mine waste	43	56
	Tailings	50	60
Phosphate	Mine waste	21	45
	Tailings	21	34
Silver	Mine waste	10	57
	Heap leach	17	53
	Tailings	11	73
Uranium	Mine waste	14	26
Zinc	Mine waste	33	69
	Tailings	33	70

Source: Charles River Associates 1985c.

tailings operations are represented in the data base. Although only 26 percent of all of the mine waste generated annually by the uranium segment is reflected in the data base, the data base generally reflects at least half of the total amount of waste generated by the waste management operations of each of the respective industry segments.

To provide estimates of the maximum amount of potentially hazardous waste generated by the mining industry segments of concern, EPA assumed that if any waste sample from a waste management operation failed a particular hazard criterion, all of the waste from that operation failed that hazard criterion. For example, if one of five samples from a tailings pond was EP toxic, EPA assumed that all waste from that tailings operation was EP toxic. Similarly, if a sample of pregnant leachate from a dump leach pile had a pH of less than or equal to 2, waste from the entire dump leach operation was considered corrosive.

Table B-2 shows the number of sampled waste management operations represented in the EPA data base that had at least one sample that was classified as hazardous. It also shows how many of these waste management operations had at least one sample classified as hazardous because it was EP toxic, corrosive, radioactive, or had high acid formation potential.

To estimate the total amount of potentially hazardous waste generated annually, EPA extrapolated results from the sampled wastes represented in the EPA data base to wastes generated by mines included in the data base and to wastes generated by mines included in the data base but not sampled by EPA.

For mines not sampled by EPA but represented in the EPA data base, EPA estimated the amount of potentially hazardous waste generated annually as follows. The annual amount of waste generated at operations at these mines,

Table B-2 Number of Sampled Waste Management
Data Base with at Least One Sample Classified as Hazardous

Mining industry segment	Number of hazardous waste management operations	EP toxic	Corrosive	High acid formation potential	Radium-226 greater than or equal to 5 pCi/g	Radium-226 greater than or equal to 20 pCi/g
Copper						
Mine waste	7	0	0	0	0	0
Dump leach waste	3	0	1	0	0	0
Tailings	12	0	0	4	0	0
Gold						
Mine waste	6	1	0	0	0	0
Heap leach waste	5	0	0	0	0	0
Tailings	4	2	0	0	0	0
Lead						
Mine waste	3	1	0	0	0	0
Tailings	3	1	0	0	0	0
Phosphate						
Mine waste	7	0	0	0	5	0
Tailings	7	0	0	0	4	1
Silver						
Mine waste	5	1	0	0	0	0
Heap leach waste	1	0	0	0	0	0
Tailings	5	1	0	1	0	0
Uranium						
Mine waste	6	0	0	0	6	5
Zinc						
Mine waste	4	0	0	0	0	0
Tailings	4	1	0	0	0	0

Source: EPA sampling results and EPA data base.

as reported in the data base, was multiplied by the percentage of sampled operations reported in the data base as having potentially hazardous waste. To estimate the amount of potentially hazardous waste generated annually by those mining operations not represented in the data base, EPA multiplied the percentage of waste found to be potentially hazardous at mines represented in the data base by the estimated amount of waste generated by the mines that were not represented in the data base. Table B-3 illustrates EPA's methodology for estimating the total amount of potentially hazardous mining waste generated annually.

One limitation of this approach is that not all of EPA's sampling data could be used in the projections of the total amount of potentially hazardous waste, i.e., only data for waste operations represented in the EPA data base were used to estimate projected amounts of waste. EPA recognizes that use of this methodology may overlook some data. For example, if EPA had sampling results showing that a sample taken from an operation that was not represented in the data base had a hazardous level of one of the properties considered hazardous in this report, no waste from such an operation in that industry segment was classified as having that property. To illustrate, one sample taken by EPA at a copper waste operation was EP toxic, but because this particular operation was not represented in the EPA data base, no waste from this industry segment is reported here to be EP toxic. A similar problem occurs with respect to the acid formation potential of wastes in the gold and silver industry segments; the analysis of minerals for these industry segments shows that a significant percentage of these tailings have high acid formation potential. However, since none of these tailings operations were located at mines represented in the EPA data base, no tailings from these segments are

Table B-3 Methodology for Estimating the Total Amount of Potentially Hazardous Mining Waste Generated Annually

Source of data	Method for determining amount of waste	Method for determining percentage of potentially hazardous waste
Sampled sites represented in EPA's data base	Site-by-site estimates for sites represented in EPA's data base	Sampling results
Non-sampled sites represented in EPA's data base	Site-by-site estimates for sites represented in EPA's data base	Percentage of all sites found to have hazardous waste
Sites not sampled and not represented in EPA's data base	Total amount of mining waste based on Bureau of Mines estimates minus amount of mining waste represented in EPA's data base	Extrapolation based on relative amount of waste found to be hazardous in mines represented in EPA's data base

considered potentially hazardous because of their high acid formation potential. Despite these anomalies, EPA decided to base its estimates on data from the sampled operations represented in EPA's data base because complete sampling data and estimates of the amount of waste generated annually were available only for these operations. In addition, EPA's data base only included information on mines that were active in 1985.

APPENDIX C

SELECTED CRITERIA ANALYZED FOR TOXIC EFFECTS

TABLE C-1

A COMPARISON OF LEVELS OF EP TOXIC METALS ALLOWED BY VARIOUS EPA STANDARDS AND CRITERIA

Metals Measured by RCRA's EP Toxicity Test	Levels Specified by 40 CFR 261.24, Characteristic of EP Toxicity, mg/l	Maximum Contaminant Levels Specified by 40 CFR 141.11, National Interim Primary Drinking Water Standards, mg/l	Levels Specified by 45 FR 79318, Nov. 20, 1980 Ambient Water Quality Criteria for the Protection of Aquatic Life, mg/l (24-hour average)
Arsenic	5.0	.05	NA
Barium	100.0	1.0	NA
Cadmium	1.0	.01	.000025
Chromium (VI)	5.0	.05	.00029
Lead	5.0	.05	.0038
Mercury	0.2	.002	.0002
Selenium	1.0	.01	0.035
Silver	5.0	.05	NA

NA - Not Applicable

TABLE C-2

ARSENIC TOXICITY TO AQUATIC BIOTA

Toxic Effect	Most Sensitive Organism Tested	Toxic Concentration, mg/l		Source
Acute toxicity (LC_{50}/EC_{50})[a]				
	Cladocera *Simocephalus serrulatus*	0.812	As^{+3}	US EPA (1980a)
	Daphnia magna	7.4	As^{+5}	US EPA (1980a)
	Minnows	27-45	As^{+3}	McKee and Wolf (1963)
Chronic toxicity	Algae[b]	2.32	As^{+3}	US EPA (1980a)
	Daphnia magna	0.91 0.52	As^{+3} Total As	US EPA (1980a) NRCC (1980)
	Bass	7.6		McKee and Wolf (1963)

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[a] The terms LC50 and EC50 refer to contaminant concentrations lethal (LC50) or causing significant toxic effects (EC50) to 50 percent of a test population within a selected test duration.

[b] 100% kill in 2 weeks.

TABLE C-3

CADMIUM TOXICITY TO AQUATIC BIOTA

Toxic Effect	Most Sensitive Organism Tested	Toxic Concentration (mg/l x 10^{-3})	Source
Acute toxicity (LC_{50}/EC_{50})[a]	Cladoceran *Simocephalus serrulatus*	3.5-35	US EPA (1980b)
	Striped bass larvae	1.0	US EPA (1980b)
Chronic toxicity	Diatoms *Asterionella formosa*	2.0	US EPA (1980b)
	Daphnia pulex	1.0	US EPA (1980b)
	Rainbow trout	0.7-130	US EPA (1980b)
	Brook trout	1.0	NRCC (1979a)

---

[a] The terms LC50 and EC50 refer to contaminant concentrations lethal (LC50) or causing significant toxic effects (EC50) to 50 percent of a test population within a selected test duration.

TABLE C-4

CHROMIUM TOXICITY TO AQUATIC BIOTA

Toxic Effect	Most Sensitive Organism Tested (freshwater)	Toxic Concentration Level (mg/l)		Source
		Cr VI	Cr III	
Acute toxicity (LC_{50}/EC_{50})[a]	Algae	0.01-0.50		US EPA (1980c)
	Watermilfoil		9.9	US EPA (1980c)
	Scud	0.067	3.1	US EPA (1980c)
	Daphnia magna	6.4	2.0-59	US EPA (1980c)
		0.016-0.7	0.33	NRCC (1980)
	Fathead minnow	17.6-66	5.0-67	US EPA (1980c)
	Benthic organisms		3.0-60	NRCC (1980)
Chronic toxicity	*Daphnia magna*		0.066	US EPA (1980c)
	Rainbow trout	0.073-0.265		US EPA (1980c)
	Fathead minnow		1.02	US EPA (1980c)

---

[a] The terms LC50 and EC50 refer to contaminant concentrations lethal (LC50) or causing significant toxic effects (EC50) to 50 percent of a test population within a selected test duration.

TABLE C-5

LEAD TOXICITY TO AQUATIC BIOTA

Toxic Effect	Most Sensitive Organism Tested	Toxic Concentration Level (mg/l)	Hardness (mg/l Cs $CaCO_3$)	Source
Acute toxicity (LC_{50}/EC_{50})[a]	Algae	0.3-30		NRCC (1979)
		0.5-1.0		US EPA (1980d)
	Invertebrates (scud)	0.124	46	US EPA (1980d)
	Daphnia magna	0.45-1.91	45-152	US EPA (1980d)
	Sticklebacks and trout	0.30	soft	NRCC (1979)
	Fathead minnow	2.4-482	20-360	US EPA (1980d)
Chronic toxicity	Algae	0.1-2.0		NRCC (1979)
	Daphnia magna	0.012-0.128	52-151	US EPA (1980d)
	Rainbow trout	0.019-0.128	19-128	US EPA (1980d)

---

[a] The terms LC50 and EC50 refer to contaminant concentrations lethal (LC50) or causing significant toxic effects (EC50) to 50 percent of a test population within a selected test duration.

TABLE C-6

MERCURY TOXICITY TO AQUATIC BIOTA

Toxic Effect	Most Sensitive Organism Tested	Toxic Concentration mg/l[a]	Compound	Source
Acute toxicity (LC_{50}/EC_{50})[b]	Phytoplankton	0.9-60	Mercury salts	McKee and Wolf (1963)
	Crayfish	0.02	$HgCl_2$	US EPA (1980e)
	Rainbow trout	155-400	$HgCl_2$	US EPA (1980e)
		29	CH_3HgCl	
Chronic toxicity	Daphnia magna	1.27-1.87	$HgCl_2$	US EPA (1980e)
		0.52-1.00	CH_3HgCl	US EPA (1980e)
	Minnow	0.01	$H_5 50_4$ $HgNO_3$	McKee and Wolf (1963)
	Algae	1,030*	$HgCl_2$	US EPA (1980e)

---

[a] Expressed as mercury, not the compound.

[b] The terms LC50 and EC50 refer to contaminant concentrations lethal (LC50) or causing significant toxic effects (EC50) to 50 percent of a test population within a selected test duration.

TABLE C-7

SELENIUM TOXICITY TO AQUATIC BIOTA

Toxic Effect	Most Sensitive Organism Tested	Toxic Concentration mg/1	
		Selenite (+4)	Selenate (+6)
Acute toxicity (LC_{50}/EC_{50})[a]	Blue-green algae	15-30	17-40
	Scud	0.34	0.76
	Fathead minnow	0.62-11.3	11.8-12.5
Chronic toxicity	*Daphnia sp.*	0.092-0.69	
	Rainbow trout	0.088	

Source: US EPA (1980f)

[a] The terms LC50 and EC50 refer to contaminant concentrations lethal (LC50) or causing significant toxic effects (EC50) to 50 percent of a test population within a selected test duration.

TABLE C-8

CYANIDE TOXICITY TO AQUATIC BIOTA

Toxic Effects	Organism Tested	Toxic Concentration mg/1
Acute toxicity (LC_{50}/EC_{50})[a]	*Daphnia pulex*	0.083
	Brook trout	0.052-0.507
Chronic toxicity	Scud	0.018
	Brook trout	0.008

Source: US EPA (1980g)

[a] The terms LC50 and EC50 refer to contaminant concentrations lethal (LC50) or causing significant toxic effects (EC50) to 50 percent of a test population within a selected test duration.

TABLE C-9

SUMMARY OF RADIATION EFFECTS

- Radiation has been demonstrated to be carcinogenic, mutagenic, and teratogenic (US EPA 1984).
- Radium poses a danger to human health because of its property as an alpha emitter, and because it is concentrated in bone tissue following absorption into the body (US EPA 1984).
- Chromosome aberrations in human lymphocytes following radiation exposure by ingestion of Ra-226 or by inhalation of Rn-222 have been demonstrated (US EPA 1984).
- An increased incidence of leukemia and osteosarcoma has been observed in patients who received injections of Ra-224 for medical purposes (US EPA 1984).
- US EPA (1984) estimated the radionuclide emissions from a reference underground uranium mine of assumed typical dimensions to be 11,500 Ci/yr as radon-222, 0.02 Ci/yr as uranium-238, and 3 x 10^{-4} Ci/yr as thorium-232. The most important emission was expected to be radon-222. The lifetime human mortality risk factor for persons residing within 2000 meters of the sources of these emissions was estimated to be on the order of 10^{-2}.
- In general, organisms of lower phyla are more resistant to ionizing radiation than are higher vertebrates (McKee and Wolf 1963).
- Radon, a decay product of radium, poses a danger to human health because it is an inert (noble) gas that diffuses into buildings where it builds up (concentrates) in the indoor air. The decay products of radon may be inhaled and retained in the lung, greatly increasing the risk of lung cancer.

TABLE C-10

EFFECTS OF ASBESTOS EXPOSURE

- Chrysotile and amphibole fibers are toxic to the bacteria *E. coli* and *S. aureus* (NRCC 1980).
- Mussels and freshwater fish have been shown to take up asbestos fibers from water and store these in muscle tissue, but the effect on mortality rates was not determined (NRCC 1980, US EPA 1980h).
- The ambient water quality criteria for the protection of human health developed by US EPA (1980h), assuming the ingestion of 2 liters per day of contaminated water, are 300,000 fibers per liter (f/l), 30,00 f/l, and 3,000 f/l for a projected cancer incidence rate of 10^{-5}, 10^{-6}, and 10^{-7}, respectively.
- Cytotoxicity of intestinal tissue has been observed following ingestion of asbestos fibers by rats (US EPA 1980h).
- Asbestosis, the noncancerous disease resulting from inhalation of asbestos fibers, is a chronic, progressive pneumoconiosis (US EPA 1980). The lowest cumulative asbestos respiratory exposure level at which severe forms of asbestosis have been detected is 25 fibers - year/cm^3 (US EPA 1980i).
- The risk of asbestosis rises with increasing asbestos exposure; the dose-response curve for asbestosis mortality can be qualitatively described as linear (US EPA 1980i).
- Several studies of worker exposure to asbestos have linked asbestos respiratory exposure to increased rates of pleural and peritoneal mesothelioma; cancer of the lung, stomach, esophagus, pharynx, colon-rectum, skin, and kidney; leukemia; and neoplasms of the digestive organs and peritoneum (US EPA 1980h).
- Several dose-response relationships have been established for asbestos exposure and human mortality from various diseases. Over 50% of the deaths among a group of 17,800 asbestos insulation workers exposed at levels of 10 to 20 f/cm^3 and studied over a 10-year period could be attributed to asbestos-related diseases. Chronic exposure at this level was shown to result in death rates from mesotheliomas from 1.3 to 4 times those of the general U.S. population of the same age and sex (US EPA 1980h).
- Among male asbestos plant workers, respiratory exposure for less than 2 years at asbestos levels of 20 or more f/cm^3 resulted in significantly increased rates of cancer deaths. Females exposed for the same duration but at the lower levels of 5 to 10 f/cm^3 exhibited significant increases in the rates of death from cancers of the lung and pleura (US EPA 1980h).

- Excess malignant respiratory disease has been reported among asbestos mine workers exposed to an average air concentration of 0.25 f/cm^3 (US EPA 1980h).

- Estimates of human exposure to asbestos for persons living within 30 km of asbestos mines or mills are 0.4 f/cm^3 compared with the average ambient urban exposure of 5×10^{-3} f/cm^3 (electron microscope visible fibers) (Suta and Levine 1979, as cited by Colgley et al. 1981).

TABLE C-11

THE SUMMARY OF EFFECTS OF DECREASING pH ON FISH

PH Range	Effects
9.0 - 6.5	Harmless to most fish; toxicity of other poisons may be affected by changes within this range.
6.5 - 6.0	Unlikely to be harmful to fish unless free carbon dioxide is present in excess of 100 mg/l; egg hatchability and growth of alevins of brook trout significantly lower at all pH levels below 6.5.
6.0 - 5.5	Egg production and hatchability of fathead minnow reduced; reduced egg production and larval survival of flagfish; roach reproduction may be affected; unlikely to be harmful to fish unless free carbon dioxide is present in excess of 20 mg/l.
5.5 - 5.0	Increased hatching time of Atlantic salmon eggs; mortality of brown trout eggs is high; threshold of tissue damage for fingerling brown trout; growth of flagfish larvae may be reduced; roach reproduction reduced at least 50 percent; may be harmful to non-acclimated salmonids if the calcium, sodium, and chloride concentrations or the temperature is low.
5.0 - 4.5	Harmful to eggs and alevins or larvae of most salmonids and white sucker, and to adults particularly in soft water containing low concentrations of calcium, sodium, and chloride; may be harmful to carp; roach recruitment impaired; fish mortalities can be expected.
4.5 - 4.0	Expected to be harmful to salmonids at all stages; likely to be harmful to tench, bream, roach, goldfish, carp, fathead minnow, bluegill; acclimation may increase resistance to these levels.
4.0 - 3.5	Lethal to most fish over extended periods.
3.5 and below	Acutely lethal to fish.

Source: Potter et al. 1982

TABLE C-12

SUMMARY OF DAMAGES TO AQUATIC ECOSYSTEMS WITH DECREASING pH

pH Range	Effects
8.0 - 6.0	Long-term changes of less than 0.5 pH units are likely to alter the biotic composition of freshwaters to some degree. The significance of these slight changes is, however, not great. A decrease of 0.5 to 1.0 pH units in the range of 8.0 to 6.0 may cause detectable alterations in community composition. Productivity of competing organisms will vary. Some species will be eliminated.
6.0 - 5.5	Decreasing pH will cause a reduction in species numbers and, among remaining species, significant alterations in ability to withstand stress. Reproduction of some salamander species is impaired.
5.5 - 5.0	Many species will be eliminated, and species numbers and diversity will be reduced. Crustacean zooplankton, phytoplankton, mamphipods, most mayfly species, and some stonefly species will begin to drop out. In contrast, several pH-tolerant invertebrates will become abundant, especially the air-breathing forms (e.g., Gyrinidae, Notonectidae, Corixidae), those with tough cuticles that prevent ion losses (e.g., Sialis lutaris), and some forms that live within the sediments (Oligochaeta, Chromomidae, and Tubificidae). Overall, invertebrate biomass will be greatly reduced.
5.0 - 4.5	Decomposition of organic detritus will be severely impaired. Autochthonous and allochthonous debris will accumulate rapidly. Most fish species are eliminated.
4.5 -	All of the above changes will be greatly exacerbated, and most fish will be eliminated.

Source: Potter et al. 1982

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APPENDIX D

GLOSSARY

GLOSSARY

ACID DRAINAGE - drainage from mines and mining wastes that has a pH ranging from below 2.0 to 4.5; the acidity is caused by the oxidation of sulfides exposed during mining, which produces sulfuric acid and sulfate salts. The acid dissolves minerals in the rocks, further degrading the quality of the drainage water.

ACID FORMATION POTENTIAL - the propensity of exposure and subsequent oxidation of naturally ocurring metal sulfides (especially iron pyrite) in ores and mining waste to produce acid. An acid environment greatly increases the leaching and mobility of toxic waste constituents, including heavy metals.

AMALGAMATION - a method of extracting a precious metal from its ore by alloying it with mercury.

AQUIFER - a water-bearing bed or structure of permeable rock, sand, or gravel capable of yielding quantities of water to wells or springs.

BACKFILLING - a waste management practice for mining waste in which the waste material is immediately used for refilling previously excavated areas.

BELOW-GRADE DISPOSAL - a disposal method for tailings in which the tailings are placed in an excavated pit so that at closure the entire deposit is below the level of the original land surface.

BENEFICIATION - the treatment of ore to concentrate its valuable constituents.

BERM - a ledge or shoulder, as along the edge of a paved road.

BIOLOGICAL ACID LEACHING - a waste pretreatment method that may be a feasible substitute for certain current dump leaching practices. The biological acid leaching process converts sulfur in the ore to elemental sulfur, which is potentially saleable and is less hazardous to the environment than sulfuric acid, the usual dump leach waste constituent.

BLOCK-CAVING - a large production low-cost method of mining, in which the greater part of the bottom area of a block of ore is undercut, the supporting pillars are blasted away, and the ore caves downward and is removed. As the block caves and settles, the cover follows.

COLLECTION TRENCH - a mitigative system used to prevent seepage from reaching ground waters or surface waters. Also effective in protecting the integrity of a tailings pond dam.

COLLOID - an extremely fine-grained material of particles having diameters of less than 0.00024 mm that can be easily suspended in solution.

CONTAINMENT SYSTEMS - a. mitigative measures that prevent leachate from entering the ground water and posing a threat to human health and the environment. These measures include: liners, cutoff walls, interceptor wells, hydraulic barriers, and grouting; b. a type of run-on/runoff control that collects onsite stormwater or dike seepage in holding or evaporation ponds for the treatment necessary for final disposal or to prepare the waste for recycling.

CUT-AND-FILL UNDERGROUND MINING (cut-and-fill stoping) - a mining method in which the ore is excavated by making successive flat or inclined slices, working upward from the level. After each slice is blasted down, all broken ore is removed and the stope is filled with waste to within a few feet of the back before the next slice is taken out. During the process, there is just enough room between the top of the waste pile and the back of the stope to provide working space.

CUTOFF WALLS - a mitigative measure employed as a containment system to prevent seepage from contaminating ground water. Walls, collars, or other structures reduce percolation of water along smooth surfaces or through porous strata.

DEWATERING - removing water from a mine by pumping or drainage. Water produced from mine dewatering may be discharged directly or indirectly to a surface stream, used in the milling process in make-up water, pumped to a tailings pond, or used on site for dust control, cooling, or drilling fluid.

DIKE STABILIZATION - a mitigative measure that controls liquids. The structural integrity of the dike or dikes constructed to confine the wastes is considered, an assessment is made of the ability of the dike system to withstand additional loads, including the weight of several layers of a capping system, and construction equipment is used to place and compact the final cover.

DIVERSION METHODS - a type of run-on/runoff control that prevents offsite water from entering a waste management site and causing erosion and flooding.

DREDGING - the various processes by which large floating machines (dredges) scoop up earth material at the bottom of a body of water, raise it to the surface, and discharge it into a pipeline or barge, return it into a pipeline or barge, or return it to the water body after the removal of ore minerals.

DUMP LEACHING - a beneficiation process in which sub-ore-grade material is leached by acid to recover copper. The material to be leached is placed directly on the ground and the leaching may continue for years or decades.

DUMP LEACH WASTE - a large-volume waste that results from the dump leaching process.

ELECTROSTATIC SEPARATION - a process of ore concentration used to separate minerals on the basis of their conductivity. The ore is charged with high voltages and the charged particles are dropped onto a conductive rotating drum. The conductive particles discharge rapidly, are thrown off, and are then collected. The nonconductive particles keep their charge, adhere to the drum by electrostatic attraction, and are removed separately.

ELECTROWINNING - recovery of a metal from an ore by means of electrochemical processes.

FINAL COVER - a mitigative measure which, when properly installed over the exposed surfaces of a waste impoundment, ensures control of erosion, fugitive dust, and surface water infiltration; promotes proper drainage; and creates an area that is esthetically pleasing and amenable to alternative level uses.

FRESHWATER INJECTION WELLS (freshwater input wells) - a mitigative measure that contains seepage, in which freshwater (water with less than 0.2 percent salinity) is pumped into wells for pressure maintenance. Used in the formation of a hydraulic barrier, and most effective under conditions of subsurface homogeneity.

FROTH FLOTATION - often referred to simply as flotation, this process is the separation of finely crushed minerals from one another by causing some to float in a froth and others to sink. Oils and various chemicals are used to activate, make flotable, or depress the minerals.

GANGUE - the valueless rock or mineral aggregates in an ore, that part of an ore that is not economically desirable but cannot be avoided in mining. It is separated from the ore minerals during concentration and is generated as tailings.

GEOCHEMICAL PROCESSES - processes that control the rate of movement of contaminants from the soluble liquid phase (seepage) to the solid phase (soil, geologic material) of the system.

GRAVITY CONCENTRATION - the separation of minerals by a concentration method operating by virtue of the differences in density of various minerals; the greater the difference in density between two minerals, the more easily they can be separated by gravity methods.

GROUND WATER - water found underground in porous rock strata and soils.

GROUT CURTAIN - a mitigative system used to prevent ground-water contamination. Seepage losses are controlled by grouting the foundation rock of a waste disposal facility. Used when waste presents a serious pollution hazard to groundwater.

HALF-LIFE - the time required for a radioactive substance to lose 50 percent of its activity by decay. Each radionuclide has a unique half-life.

HAZARDOUS WASTE - a solid waste, or combination of solid wastes, which, because of its quantity, concentration, or physical, chemical, or infectious characteristics, may (1) cause, or significantly contribute to, an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness; or (2) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, disposed of, or otherwise managed.

HEAP LEACHING - an extraction process in which ore is leached by cyanide to recover gold and silver, or by other reagents to recover uranium. The material to be leached is placed on a pad; the volume of material leached is smaller than in the dump leaching process. Leaching continues for months.

HEAP LEACH WASTE - a large-volume waste generated by the heap leaching process.

HYDRAULIC BARRIERS - a mitigative measure used to prevent ground-water contamination. A barrier used in conjunction with interceptor walls is established downgradient of an embankment to prevent seepage losses through the foundation of a waste disposal facility.

HYDRAULIC HEAD - the height of a free surface of a body of water above a given subsurface point.

HYDROGEOLOGIC EVALUATION - a detection and inspection measure used in combination with ground-water monitoring at a waste disposal or tailings pond facility to identify potential pathways of leakage and contamination by ground water; determine whether contamination of ground-water has occurred and, if so, the extent of contamination. If contamination has occurred, this evaluation is used to generate data about factors such as the size, depth, and rate of flow of a contaminated plume to facilitate implementation of a mitigative strategy.

HYDROLOGIC PROCESSES - geologic phenomena that determine the critical flow paths and velocities that control the leachate seepage from a waste disposal area.

INTERCEPTOR WALLS - a mitigative measure used to prevent ground-water contamination. Interceptor walls installed at points that intersect the plumes of contaminated seepage control seepage losses through the foundation of a waste disposal facility.

ISOTOPE (nuclide) - any of two or more species of atoms of a chemical element with the same atomic number and position in the periodic table and nearly identical chemical behavior, but with differing atomic mass or mass number and different physical properties.

LEACHATE - 1) the beneficiation solution (pregnant liquor) obtained from heap leach and dump leach processes; 2) the liquid resulting from water percolating through, and dissolving materials in, waste.

LEACHATE COLLECTION, REMOVAL, AND TREATMENT SYSTEMS - mitigative measures used on lined waste piles to prevent the leachate from building up above the liner. Leachate collection prevents the buildup of water over the liner and thus prevents deformation of piles and overflow of the containment system. Collected waste is treated and disposed of by treatment methods such as neutralization, precipitation, and flotation.

LINERS - a mitigative measure used to prevent ground-water contamination in which synthetic natural clay, or bentonite materials that are compatible with the wastes are used to seal the bottom of tailings ponds and waste piles.

MAGNETIC SCAVENGING (MAGNETIC SEPARATION) - the separation of magnetic materials from nonmagnetic materials, using a magnet. Magnetic scavenging is an important process in the beneficiation of iron ores in which the magnetic mineral is separated from nonmagnetic material; for example, roasted pyrite from sphalenite.

MILL TAILINGS - the waste rock (gangue) discarded after ore milling. See tailings.

MINE WASTE - a large-volume waste consisting of the soil or rock generated by mining operations during the process of gaining access to an ore or mineral body. The waste includes the overburden from surface mines, underground mine development rock, and other waste rock.

MINE WASTE PILES - a waste management practice used for mine waste or the area where mine waste or spoil materials are disposed of or piled.

MINE WATER - a large-volume waste consisting of the water that infiltrates a mine and is subsequently removed to facilitate mining.

MINE WATER PONDS - impoundments used to hold mine water prior to evaporation, recycling, or discharge.

NPDES - National Pollutant Discharge Elimination System, EPA's system of permits for controlling the discharge of water pollutants to surface waters.

OPEN-CAST MINING - a surface mining method in which the overburden is removed and minerals are extracted in a series of regular slices called cuts and the overburden of each subsequent cut is replaced into the void of the preceding cut. This method is primarily used in the mining of coal.

OPEN-CUT MINING (OPEN-PIT MINING) - a surface mining method involving the removal of the overburden, and breaking and loading the mineral, as happens in a stone quarry. This method is primarily used for metalliferous ores such as iron and copper.

OPEN-STOPE MINING - a method of stoping in which no regular artificial method of support is employed, although occasional props or cribs may be used to hold local patches of insecure ground. The walls and roof are self-supporting, and open stopes can be used only where the ore and wall rocks are firm. This method is usually confined to small ore bodies because the length of unsupported span that will stand without breaking is limited.

PLACER MINING - a form of mining in which a gravel deposit containing gold is washed to extract the gold.

POND-SEDIMENT REMOVAL - a mitigative measure used to remove the sediment that builds up in wastewater retention ponds.

OVERBURDEN - consolidated or unconsolidated material overlying the mined area.

PICOCURIE - a unit of radioactivity defined as 0.037 disintegrations per second, and abbreviated as pCi.

POTENTIALLY HAZARDOUS WASTES - wastes that have characteristics that may pose a threat to human health or the environment.

PRECIPITATION - 1) a process of separating mineral constituents from a solution by means of a reagent; 2) rain, snow, or hail.

QUARRYING - a method of surface mining used for stone or mineral deposits. This method is primarily used for non-metallic materials such as limestone and building stone.

RCRA - Resource Conservation and Recovery Act, the legislation under which EPA regulates hazardous waste.

RCRA SUBTITLE C CHARACTERISTICS - criteria used to determine if an unlisted waste is a hazardous waste under Subtitle C of RCRA:

- corrosivity - a solid waste is considered corrosive if it is aqueous and has a pH less than or equal to 2 or greater than or equal to 12.5 or if it is a liquid and corrodes steel at a rate greater than 6.35 mm per year at a test temperature of 55°C

- EP toxicity - a solid waste exhibits the characteristic of EP (extraction procedure) toxicity if, after extraction by a prescribed EPA method, it yields a metal concentration 100 times the acceptable concentration limits set forth in EPA's Primary Drinking Water Standards.

- ignitability - a solid waste exhibits the characteristic of ignitability if it is a liquid with a flashpoint below 60°C or a non-liquid capable of causing fires at standard temperature and pressure.

- reactivity - a waste is considered reactive if it reacts violently, forms potentially explosive mixtures, or generates toxic fumes when mixed with water, or if it is normally unstable and undergoes violent change without deteriorating.

RADIONUCLIDE (radioisotope) - an unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation.

RADIUM-226 - a radioactive daughter product of the decay of uranium-238. Radium is present in all uranium-bearing ores; it has a half-life of 1620 years.

RETORTING OF OIL SHALE - the heat-dependent distillation process in which oil is extracted from the raw shale.

REVEGETATION - the third step in the final cover procedure of a reclamation and closure system, revegetation is used during the active operation of the tailings pond and at closure. Regrading, contouring, and revegetation of tailings areas prevent erosion, stream turbidity and sedimentation, and provide dust control.

RIP-RAP - a foundation or sustaining wall of stones thrown together irregularly.

ROOM-AND-PILLAR MINING - a method of mining used to mine coal and metal, in which the roof is supported by pillars left at regular intervals.

RUN-ON/RUNOFF CONTROL - a mitigative measure used to control liquids and involving diversion methods and runoff acceleration practices.

RUNOFF ACCELERATION PRACTICES - a type of run-on/runoff control that reduces ground-water pollution by preventing the ponding or percolation of rainfall on wastepiles.

SECURITY SYSTEMS - a mitigative measure used for the security of control systems and protection of the public that may include the posting of "No Trespassing" signs, locked gates, security guards, and fencing.

SEEPAGE COLLECTION SYSTEMS - mitigative measures that control seepage by (1) restricting seepage outflow, or (2) using drainage methods to discharge the seepage without the danger of piping of material or buildup of a high ground-water elevation within the embankment.

SHEEPFOOT ROLLER - an earth compaction machine with a roller of "feet" used to compact by striking the earth repeatedly.

SLIMES - a material of extremely fine particles encountered in the treatment of ore. Primary slimes are extremely fine particles derived from ore, associated rock, or clay. They are usually found in old dumps and in ore deposits that have been exposed to climatic action; they include clay, alumina, hydrated iron, near-colloidal common earths, and weathered feldspars. Secondary slimes are very finely ground minerals from the true ore.

SLURRY WALLS - a seepage collection/blockage mitigative system. Seepage losses are controlled by grouting the walls of a waste disposal facility with a slurry compound of cement and water. This system is used when waste presents a serious pollution hazard to ground water.

SMCRA - Surface Mining Control and Reclamation Act.

SMELTER SLAG - the rough vesicular lavalike waste remaining after the processing of ore and minerals.

SOLVENT EXTRACTION - a method of separating one or more substances from a mixture, by treating a solution of the mixture with a solvent that will dissolve the required substance or substances, leaving the others.

SQUARE-SET STOPING - a method of stoping in which the walls and back of the excavation are supported by regular framed timbers forming a skeleton that encloses a series of connected, hollow, rectangular prisms in the space formerly occupied by the excavated ore and providing continuous lines of support in three directions. The ore is excavated in small, rectangular blocks just large enough to provide room for standing a set of timber. This method is most applicable in mining deposits in which the ore is structurally weak. The primary function of the square sets is to furnish temporary support only for loose fragments of rock and to offer a passageway to the working face. Permanent support for the stope walls is supplied by filling the sets with broken waste rock.

STOPE - an excavation where the ore is drilled, blasted, and removed by gravity through chutes to ore cars on the haulage level below. Stopes require timbered openings (manways) to provide access for men and materials. Raises connect a stope to the level above and are used for ventilation, convenience in getting men and materials into the stope, and admitting backfill.

STRIP MINING - mines from which minerals that lie near the surface are extracted using a cutting technique by which long, shallow cuts are made in the ground after the removal of overburden. These mines are primarily used in the mining of coal.

SURFACE WATER - water that rests on the surface of the rocky crust of the earth.

SURFACE WATER DIVERSION - this control system consists of canals, channels, or pipes that totally or partially surround a waste management site or leaching operation and divert surface water flow around it and back into the natural system channel downgradient of the waste area. The most important functions of diversion ditches are to reduce the volume of water contacting the waste (run-on) and to minimize downstream environmental damage (runoff).

TAILINGS - a large-volume waste consisting of the materials remaining after the valuable constituents (also termed values) of the ore have been removed by physical or chemical beneficiation, including crushing, grinding, sorting, and concentration by a variety of methods.

TAILINGS PONDS - a waste management practice for tailings consisting of an area closed at the lower end by a constraining wall or dam to which mill tailings are run. The size and design of the ponds vary widely by industry segment and location.

TAILINGS SLURRY - the method used to transport tailings from the mill. The slurry consists of 50 to 70 percent (by weight) liquid mill effluent and 30 to 50 percent solids (clay, silt, and sand-sized particles).

THICKENED DISCHARGE - a disposal method for tailings in which the tailings slurry is partially dewatered and discharged from a single point. The result is a gently sloping, cone-shaped deposit.

UMTRCA - Uranium Mill Tailings Radiation Control Act.

UNDERGROUND MINE DEVELOPMENT ROCK - rock removed while sinking shafts or accessing or exploiting the ore body.

VALUE - the valuable constituents of an ore.

WASTE ROCK - rock that must be broken and disposed of to gain access to and excavate the ore; valueless rock that must be removed or set aside before the milling process.

WASTE STABILIZATION - a mitigative measure used to control liquids; proper consolidation and stabilization of the waste are necessary to ensure long-term support for the final cover. The first step in stabilization of tailings is dewatering the wastes. The wastes are then tested to determine the amount of settlement of the wastes due to compression from the final cover system and the construction used in applying the cover system components.

WASTE UTILIZATION - a current mining waste disposal practice that involves: (1) the extraction of economically valuable amounts of metals or minerals in the waste, and (2) the use of this waste material for productive purposes.

WASTEWATER TREATMENT - a mitigative measure used to control liquids. The wastewater that remains onsite after active mining and milling processes is treated and then either discharged or transported to a licensed disposal site.

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